UdG - EPS

# SOCRATES-ERASMUS PROJECT

**STUDIES:** ELECTRONICS ENGINEERING

**Title:** MANIPULATOR CONTROL BOARD

**Document:** **Report**

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**Department:** Computer and Engineering
**Area:** MRC

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# 1 INTRODUCTION

## 1.1 Presentation of University of Girona

The University of Girona was established in 1991 in accordance with the Establishment Act approved by the Parliament of Catalonia on the basis of the initiative begun in 1968 which was manifested in the establishment of technical, science, humanities and social sciences studies.

The UdG has seven teaching centres: the Faculty of Sciences, Faculty of Business and Economic Sciences, Faculty of Education Sciences, Faculty of Law, Faculty of Arts, Advanced Polytechnic School and University School of Nursing.

I am studying ETIEI in the Advanced Polytechnic School, in other words, Electronic Engineering. ETIEI is the acronym of “Enginyeria Tècnica Industrial en Electrònica Industrial”. I am in the third and last year of my degree, and to finish it I have to do the “final degree project”.

Thanks to the Socrates-Erasmus exchange I have had the possibility of doing it in a foreign country and have the chance of improve my English, discover another culture and life style, get more experience and, of course, grow as a person.

## 1.2 Why the University of Wales, Newport?

The University of Wales, Newport has been involved in higher education for more than 80 years and attracts students for all over the world.

The Mechatronics Research Centre at Newport was established in 1994 to provide a focus for research in the area where the University had already established a reputation for delivering undergraduate programmes and specialist industrial training courses. Research programmes undertaken by the centre contain a strong element of intelligent systems. Within this generic area there are thematic research groupings of guidance and control, fault detection and signal processing.

### 1.3 About the project

The Mechatronics Research Centre (MRC) owns a small scale robot manipulator called a Mini-Mover 5. This robot arm is a microprocessor-controlled, six-jointed mechanical arm designed to provide an unusual combination of dexterity and low cost.

The Mini-Mover-5 is operated by a number of stepper motors and is controlled by a PC parallel port via a discrete logic board. The manipulator also has an impoverished array of sensors.

This project requires that a new control board and suitable software be designed to allow the manipulator to be controlled from a PC. The control board will also provide a mechanism for the values measured using some sensors to be returned to the PC.

On this project I will consider: stepper motor control requirements, sensor technologies, power requirements, USB protocols, USB hardware and software development and control requirements (e.g. sample rates).

In this report we will have a look at robots history and background, as well as we will concentrate how stepper motors and parallel port work.

# 2 ROBOTS

## 2.1 Definition

In practical usage, a robot is a mechanical device which performs its tasks either according to direct human control, partial control with human supervision, or completely autonomously. Robots are typically used to do tasks that are too dull, dirty, or dangerous for humans. Industrial robots used in manufacturing lines used to be the most common form of robots, but that has recently been replaced by consumer robots cleaning floors and mowing lawns. Other applications include toxic waste cleanup, underwater and space exploration, surgery, mining, search and rescue, and searching for IEDs and land mines. Robots are also finding their way into entertainment and home health care.

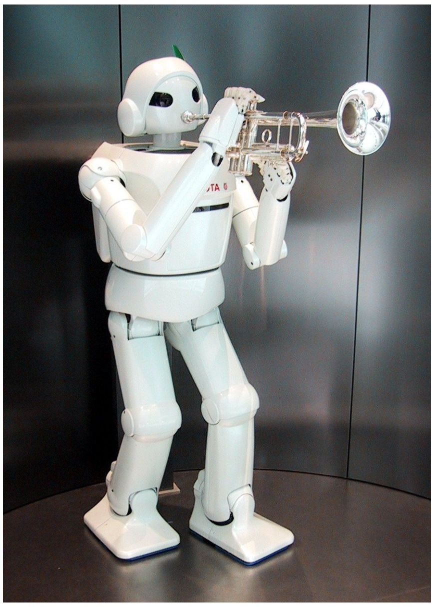


Figure 1. A humanoid robot playing the trumpet.

## 2.2 Robots basics

The vast majority of robots have several qualities in common. First of all, almost all robots have a movable body. Some only have motorized wheels, and others have dozens of movable segments, typically made of metal or plastic. Like the bones in your body, the individual segments are connected together with joints.

Robots spin wheels and pivot jointed segments with some sort of actuator. Some robots use electric motors and solenoids as actuators; some use a hydraulic system; and some use a pneumatic system (a system driven by compressed gases). Robots may use all these actuator types.

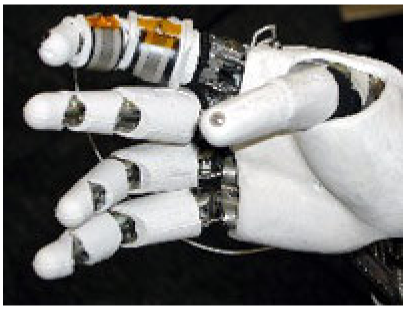


Figure 2. A robotic hand, developed by NASA, is made up of metal segments moved by tiny motors. The hand is one of the most difficult structures to replicate in robotics.

A robot needs a power source to drive these actuators. Most robots either have a battery or they plug into the wall. Hydraulic robots also need a pump to pressurize the hydraulic fluid, and pneumatic robots need an air compressor or compressed air tanks.

The actuators are all wired to an electrical circuit. The circuit powers electrical motors and solenoids directly, and it activates the hydraulic system by manipulating electrical valves. The valves determine the pressurized fluid's path through the machine. To move a hydraulic leg, for example, the robot's controller would open the valve leading from the fluid pump to a piston cylinder attached to that leg. The pressurized fluid would extend the piston, swivelling the leg forward. Typically, in order to move their segments in two directions, robots use pistons that can push both ways.

The robot's computer controls everything attached to the circuit. To move the robot, the computer switches on all the necessary motors and valves. Most robots are reprogrammable - to change the robot's behaviour, you simply write a new program to its computer.

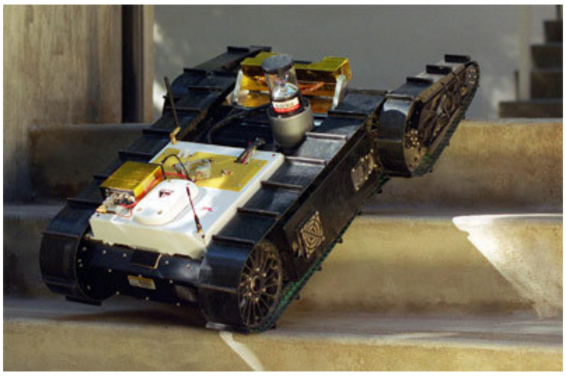


Figure 3. NASA's Urbie climbing stairs.

Not all robots have sensory systems, and few have the ability to see, hear, smell or taste. The most common robotic sense is the sense of movement - the robot's ability to monitor its own motion. A standard design uses slotted wheels attached to the robot's joints. A LED on one side of the wheel shines a beam of light through the slots to a light sensor on the other side of the wheel. When the robot moves a particular joint, the slotted wheel turns. The slots break the light beam as the wheel spins. The light sensor reads the pattern of the flashing light and transmits the data to the computer. The computer can tell exactly how far the joint has swivelled based on this pattern. This is the same basic system used in computer mice.

These are the basic nuts and bolts of robotics. Roboticists can combine these elements in an infinite number of ways to create robots of unlimited complexity.

### 2.3 The robotic arm

The term robot comes from the Czech word robota, generally translated as "forced labour." This describes the majority of robots fairly well. Most robots in the world are designed for heavy, repetitive manufacturing work. They handle tasks that are difficult, dangerous or boring to human beings.

Figure 4. Robotic arms are an essential part of car manufacturing.

The most common manufacturing robot is the robotic arm. A typical robotic arm is made up of seven metal segments, joined by six joints. The computer controls the robot by rotating individual step motors connected to each joint (some larger arms use hydraulics or pneumatics). Unlike ordinary motors, step motors move in exact increments. This allows the computer to move the arm very precisely, repeating exactly the same movement over and over again. The robot uses motion sensors to make sure it moves just the right amount.

An industrial robot with six joints closely resembles a human arm - it has the equivalent of a shoulder, an elbow and a wrist. Typically, the shoulder is mounted to a stationary base structure rather than to a movable body. This type of robot has six degrees of freedom, meaning it can pivot in six different ways. A human arm, by comparison, has seven degrees of freedom.

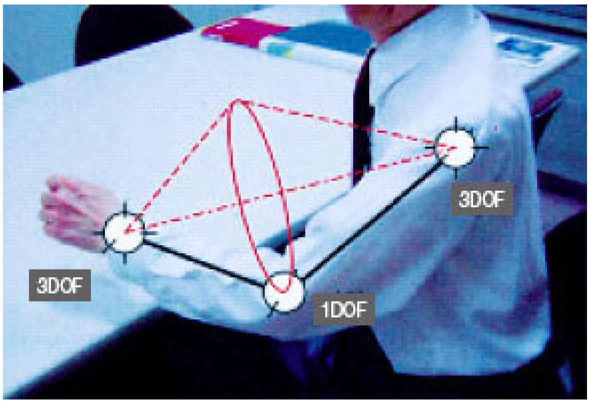



Figure 5. Locations of the seven degrees of freedom (DOF) in the human arm. Even after fixing the hand position and orientation, the elbow can move along a part of the circle shown in the figure, implying that the arm has one redundant degree of freedom.

Your arm's job is to move your hand from place to place. Similarly, the robotic arm's job is to move an end effector from place to place. You can outfit robotic arms with all sorts of end effectors, which are suited to a particular application. One common end effector is a simplified version of the hand, which can grasp and carry different objects. Robotic hands often have built-in pressure sensors that tell the computer how hard the robot is gripping a particular object. This keeps the robot from dropping or breaking whatever it's carrying. Other end effectors include blowtorches, drills and spray painters.

Industrial robots are designed to do exactly the same thing, in a controlled environment, over and over again. For example, a robot might twist the caps onto peanut butter jars coming down an assembly line. To teach a robot how to do its job, the programmer guides the arm through the motions using a handheld controller. The robot stores the exact sequence of movements in its memory, and does it again and again every time a new unit comes down the assembly line.

Most industrial robots work in auto assembly lines, putting cars together. Robots can do a lot of this work more efficiently than human beings because they are so precise. They always drill in the exactly the same place, and they always tighten bolts with the same amount of force, no matter how many hours they've been working. Manufacturing robots are also very important in the computer industry. It takes an incredibly precise hand to put together a tiny microchip.

### 2.4 Future prospects

Some scientists believe that robots will be able to approximate human-like intelligence in the first half of the 21st century. Even before such theoretical intelligence levels are obtained, it is speculated that robots may begin to replace humans in many labour-intensive career fields.

One might think of these robots collectively as a new "robot proletariat" or working class, which will enable humans to concern themselves mainly with ruling the means of production (such as farm equipment and factories) and enjoying the fruits of robots' labour. Such a shift in the production, distribution, and consumption of goods and services would represent a radical departure from current socio-economic systems, and in order to avoid poverty normally caused by unemployment and to be allowed to partake in the fruits of robotic labour, the human proletariat would need to overthrow the ruling class, in full accordance with Marx's predictions.

Robotics will probably continue its spread in offices and homes, replacing "dumb" appliances with smart robotic equivalents. Domestic robots capable of performing many household tasks, described in science fiction stories and coveted by the public in the 1960s, are likely to be eventually perfected.

There is likely to be some degree of convergence between humans and robots. Some humans are already cyborgs with some body parts and even parts of the nervous system replaced by artificial analogues, such as pacemakers. In many cases the same technology might be used both in robotics and in medicine.

# 3 MINIMOVER-5

## 3.1 Background

The TeachMover robot arm is a microprocessor-controlled, six-jointed mechanical arm designed to provide an unusual combination of dexterity and low cost.

Developmental work with computer-controlled manipulators was limited, at first, to laboratories at a few research-oriented universities in the USA and overseas.

Industry has applied a great deal of this research to factory situations, and as a result thousand of robot arms now help to manufacture products we use daily. Industrial robots spot-weld automobile bodies, feed material into punch-presses, spray-paint metal and plastic components, empty injection-molding machines, and perform many other factory jobs.

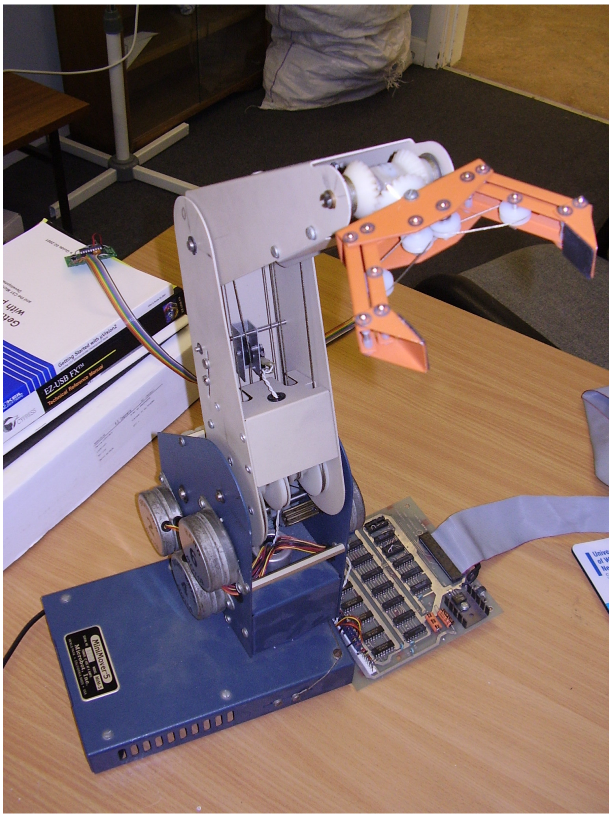


Figure 6. The TeachMover robot arm.

## 3.2 How the Teachmover is built

### 3.2.1 Major components

The Teachmover's major structural components are shown in Figure 7. The microprocessor card is housed in the base. The body swivels relative to the base on a hollow shaft attached to the base. This shaft is called the base joint.

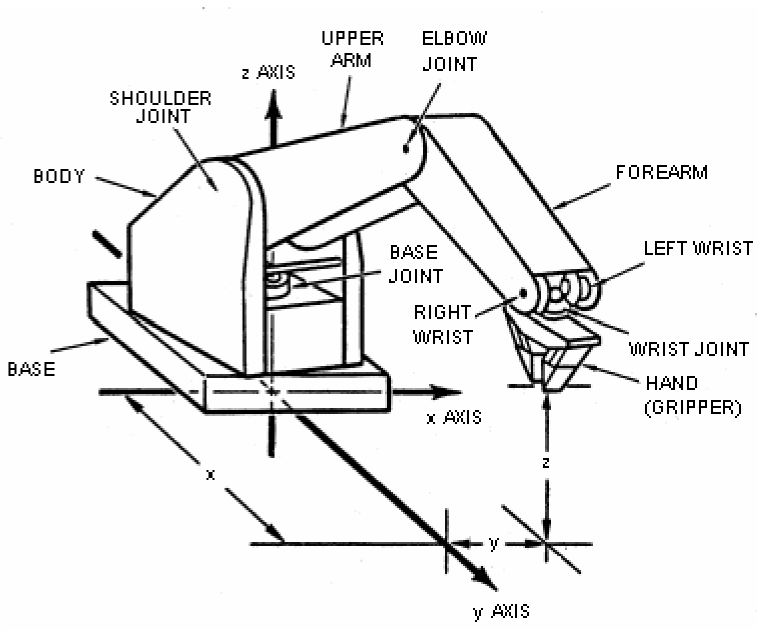



Figure 7. Major structural components.

Six stepper motors with gear assemblies are mounted on the body and control each of the six joints. The power wires for the motors pass from the computer card in the base through a hollow shaft to the body. This arrangement provides a direct cable-drive system.

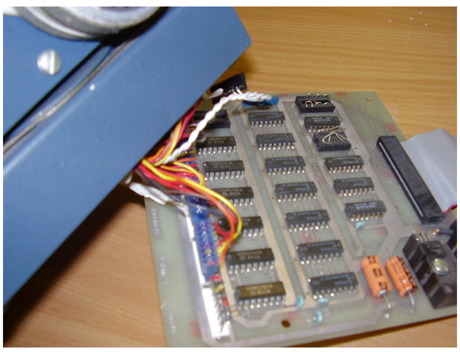


Figure 8. The original card.

The upper arm is attached to the top of the body and rotates relative to the body on shaft called the shoulder joint. Similarly, the forearm is attached to the upper arm by another shaft know as the elbow joint.

Finally, the hand, also called the gripper, is attached to the forearm by two wrist joints. Two separate motors operate wrist joints to control the pitch and roll of the hand.

The Teachmover has a lifting capacity of one pound when fully extended, and a resolution (the smallest amount the arm can be made to move) of 0.011 inches. The end of the hand can be positioned anywhere within a partial sphere with a radius of 17 inches, as shown in Figure 9. The maximum speed is from 2 to 7 inches per second, depending upon load (weight of the object being handled). Detailed performance characteristics of the Teachmover are given in Table 1.

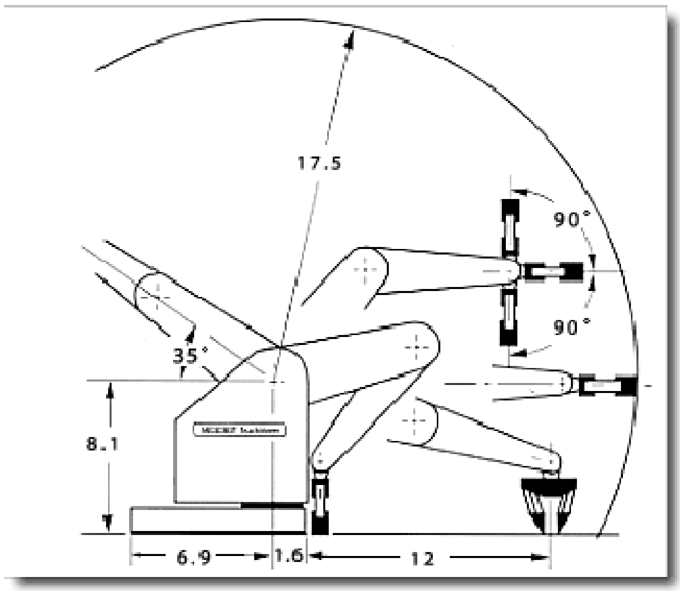



Figure 9. Operating Envelope of the Teachmover Arm

In general, the base, the body, and all the extension members are hollow sheet-metal parts which are light in weight but strong. All members are connected to each other by means of shafts, or axles, passing through bushings mounted on the members.

| Motion | Max Range of Mtn | Speed (full Load) |
|---|---|---|
| Base | ±90º | 0.37 rad/sec |
| Shoulder | +144º, -35º | 0.15 rad/sec |
| Elbow | 0º, -149º | 0.23 rad/sec |
| Wrist Roll | ±270º | 1.31 rad/sec |
| Wrist Pitch | ±90º | 1.31 rad/sec |
| Hand | 0-3 in | 8 lb/sec [1] |

Table 1. TeachMover performance characteristics.

### 3.2.2 Cable drive systems

Most robot arms have at least some of the drive motors mounted on the extension members (forearm, upper arm, hand). Unfortunately this adds to the weight of those members, and means that the other motors – those that drive the extension members – need to be larger and more expensive than would otherwise be required.

If you look for the motors on the Teachmover's extension members, you won't find any. That's because all six drive motors are mounted in the body. This minimizes the weight of the extension members and keeps the motor workload requirements as low as possible. To reduce the number of moving parts, all six drive gears are mounted on the same shaft.

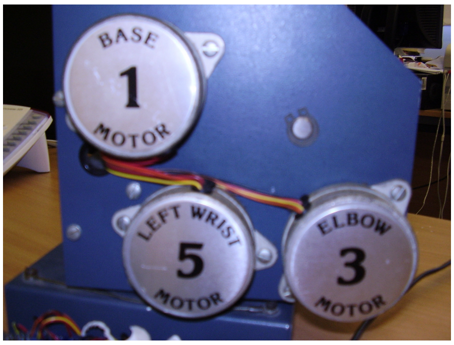



Figure 10. Three of the six stepper motors.

[1] This is given in lbs/sec rather than in/sec because as the gripper closes it no longer moves, but instead builds up gripping force. It takes 0.37 sec to build up the maximum force of 3 lbs.

A unique system is employed to manipulate the arm members. From the drive system in the body, aircraft-quality cables extend to the base, upper arm, forearm, and hand, as you can see looking at Figure 11. This cable design is an adaptation and refinement of the “tendon technology” used in aircraft, high speed printers and other types of equipment. Each cable is wound around the hub of the drive gear. This serves not only to provide a take-up drum for the cable, but also gives the proper gear-reduction ratios for each of the six drives.

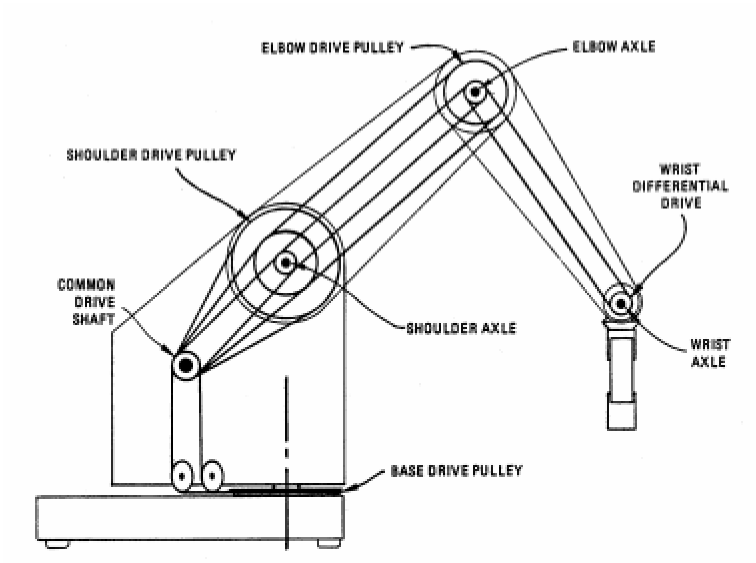



Figure 11. Cable drive system.

Now, let’s look briefly at how each of the cable drives is constructed. On the hubs of the drive gears there is a set screw on each hub pinning the cable tightly in a groove cut into the hub. As the drive gear turns, the hub is pulling, or winding, one-half of the cable while unwinding the other half (see figure 11).

### 3.2.2.1 Base Drive

The base drive causes the body to rotate on the vertical base axle by driving a large pulley mounted on the base. Two small pulleys, located at the bottom of the body, change the base cable direction so that the cable feed is tangent to the surface of both the drive drum and the base pulley. The termination of the cable is in a clamp fastened by two screws on one side of the base.

### 3.2.2.2 Shoulder Drive

The shoulder cable causes the upper arm to rotate on the horizontal shoulder axle. This cable passes around a drive pulley on the shoulder shaft, and then terminates on the upper arm housing. At the termination point, there are two screws. These screws are used to maintain the cable under tension.

If you rotate the shoulder joint again you will notice that shoulder rotation always causes equal and opposite elbow and wrist rotation so that the orientation of the hand remains unchanged. This feature is built into the Teachmover's cabling design to make sure that the hand can hold a glass of liquid while the shoulder rotates without spilling the liquid.

#### 3.2.2.3 Elbow Drive

The elbow cable causes the elbow to rotate on the horizontal elbow axle. This cable first passes around an idler pulley on the shoulder axle and then around a drive pulley of the same diameter attached to the elbow axle. The cable terminates at a tension mechanism on the forearm housing. If you rotate the elbow manually you will notice that the wrist rotates the same amount in the opposite direction, thus maintaining hand orientation.

In rotating the elbow manually you may have noticed something else: when the elbow rotates, the hand opens and closes. Designing cabling to prevent this from happening mechanically would have added undesirable complexity.

#### 3.2.2.4 Wrist Drive

The right and left wrist cables cause the hand to "roll" and "pitch" relative to the forearm. These cables together control the wrist joint (Figure 12). Both cables pass round idler pulleys on the shoulder axle and the elbow axle, then around the hubs of bevel gears located on the wrist axle. Tension is maintained in both cables by means of turnbuckles.

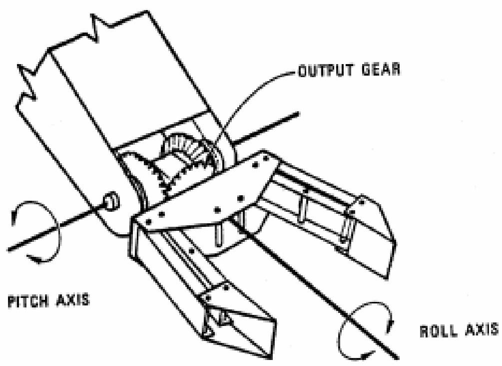



Figure 12. The wrist joint.

The two bevel gears on the wrist axle mesh with the outputs gear on the hand axle. This configuration forms a differential gear set.

To see how this differential works, turn the drive gears so the left and right wrist cables both move in the same direction. You can see the wrist gears control the pitch of the hand. Turning the drive gears so the wrist cables move in opposite directions controls the roll of the hand.

#### 3.2.2.5 Hand Drive

The hand cable system is shown in Figure 13. Attached to the output gear of the differential gear set, the hand housing holds two pairs of links, and each pair of links terminates in the gripper. The housing, the links, and the gripper are attached to each other by small pins. Torsion springs located on the pins attach the links to the hand housing and provide the return force to open the hand housing and provide the return force to open the hand as the hand cable is slackened.

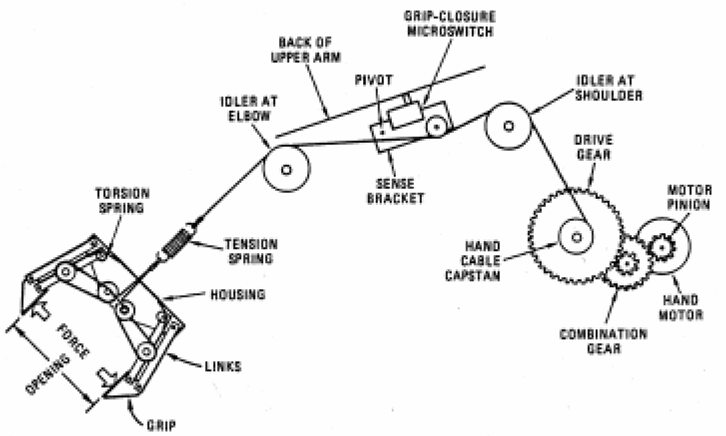



Figure 13. Hand cabling diagram.

The hand cable is attached to the hand drive drum located in the body. The cable passes over an idler pulley located on the shoulder axle, and the over and idler pulley mounted on a sensing bracket found inside the upper arm housing. This sensing bracket is also called the grip micro switch. This switch goes on when the cable tension increases just beyond the point where the hand closes on an object (or on itself).

Attached to the other end of the tension spring, and in line with the hand cable, there are two separate link-drive cables. These cables pass over two guides pulleys in the wrist yoke and then through the centre of the hollow hand axle. When the cables emerge from the hand axle, they pass over separate idler pulleys mounted in the base of the hand. They then pass around idler pulleys mounted on the inner links of the hand, and return to and terminate on the shafts of two pulleys mounted on the hand base. This arrangement forms two block-and-tackle devices that augment the gripping force of the hand. The use of identical cabling on both links provides for symmetrical hand closure.

The tension spring mounted in series with the hand-cable drive assembly permits gripping force to be built up by the position-controlled drive motor once the hand has closed.

### 3.2.3 Cable tension adjustments

After a period of extended use or after an extreme overload, tension adjustments may slip. The relaxed half of a cable should not have noticeable slack. If a cable does develop slack, then the cable needs to be tightened.

Be careful not to put excessive tension in the cable. Tight cables can cause the motor to slip with a loss of orientation between the microprocessor and the arm position.

## 3.3 How the stepper motors operate

### 3.3.1 Fundamentals

Each of the cable drives is controlled by a stepper motor. The motors used have 4 coils, each driven by a power transistor. The drive is digital, with the transistors either turned on or turned off to obtain the desired pattern if currents in the motor windings. By changing the pattern of currents, a rotating magnetic field is obtained inside the motor that causes the motor to rotate in small increments or steps.

The relationship between motor steps and actual joint rotation is given in Table 2.

| Motor | Joint | Steps per degree | Steps per radian |
|---|---|---|---|
| 1 | Base | 19.64 | 1125 |
| 2 | Shoulder | 19.64 | 1125 |
| 3 | Elbow | 11.55 | 672 |
| 4 | Right wrist | 4.27 | 244.4 |
| 5 | Left wrist | 4.27 | 244.4 |

Table 2. Motor steps and joint rotation.

### 3.3.2 Speed-Torque considerations

The torque output (lifting capacity) of the stepper motors used on the Teachmover varies with their speed. At slow speeds, maximum torque is obtained. Above a critical high speed the motors suddenly slip, and no torque is obtained. Motor slippage can cause a discrepancy between where the arm is and the where the computer program think it is, and this may result in unpredictable performance.

The torque required by the motors of the Teachmover also depends on the configuration of the arm and the load held in the hand. This relation is a complex trigonometric expression involving the lengths and the weights of all the arm members. Instead of solving such an expression before each arm movement to determine the maximum allowable speed, it is simple to program for the worst case.

The worst case is when the member of the arm are at maximum horizontal extension, requiring the maximum motor torque. All other configurations will require less motor torque. With the arm fully extended but with no load, the torque on all the motors is the same and motor speed can be as high as 400 half-steps per second. Above this speed the motors will slip, and the torque will be zero. With the arm carrying the maximum rated load (that is with the arm lifting 16 ounces) the torque on all the motors (except the base motor, which does not lift) is approximately equal, and maximum speed without slippage is 99 half-steps per second. At half rated load (8 ounces), maximum speed without slippage is 206 half-steps per second. These figures will become important later, when we discuss the commands you can use to control the speed of the Teachmover arm.

### 3.3.3 Motor control

Moving the arm from one position to another often requires rotation of more than one joint. In such cases, the motion can, in principle, be accomplished in either of two ways: the joints can be rotated sequentially or simultaneously. For example, as shown in Figure 14, motion of the arm from A to C can be accomplished through separate, sequential motions of the elbow and then the shoulder (A to B, then B to C), or through a coordinated motion in which the elbow and shoulder joints move simultaneously (A to C).

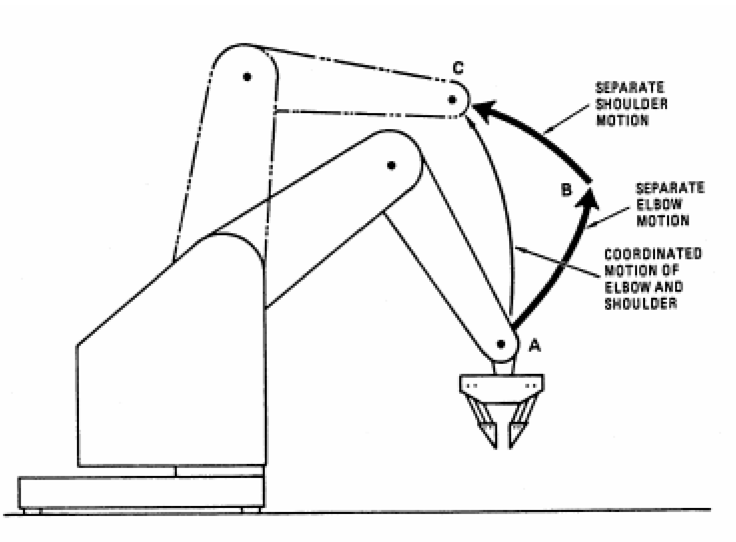



Figure 14. Coordinated versus Sequential Motions.

In general, coordinated motion is both smoother and faster than sequential motion. Teachmover firmware is programmed to produce coordinated motion whenever two or more motors are needed to move the arm from one recorded position to the next. To accomplish the coordination, the motor steps are timed so that each motor is pulsed at regular intervals during the full duration of the move.

# 4 STEPPER MOTOR

## 4.1 Introduction

In motion control, in electronic terms, means to accurately control the movement of an object based on either speed, distance, load, inertia or a combination of all these factors. There are numerous types of motion control systems, including stepper motors, linear step motor, DC brush, brushless, servo, brushless servo and more. This chapter will concentrate on stepper motor technology.

## 4.2 Working principles

Stepping motors can be viewed as electric motors without commutators. Typically, all windings in the motor are part of the stator, and the rotor is either a permanent magnet or, in the case of variable reluctance motors, a toothed block of some magnetically soft material. All of the commutation must be handled externally by the motor controller, and typically, the motors and controllers are designed so that the motor may be held in any fixed position as well as being rotated one way or the other. Most steppers, as they are also known, can be stepped at audio frequencies, allowing them to spin quite quickly, and with an appropriate controller, they may be started and stopped "on a dime" at controlled orientations.

In theory, a stepper motor is a marvel in simplicity. It has not brushes or contacts. Basically it is a synchronous motor with the magnetic field electronically switched to rotate the armature magnet around. It is used when something has to be positioned very precisely or rotated by an exact angle.

A stepper motor is an electromechanical device which converts electrical pulses into discrete mechanical movements. The shaft or spindle of a stepper motor rotates in discrete step increments when electrical command pulses are applied to it in the proper sequence. The motors rotation has several direct relationships to these applied input pulses. The sequence of the applied pulses is directly related to the direction of motor shafts rotation. The speed of the motor shafts rotation is directly related to the frequency of the input pulses and the length of rotation is directly related to the number of input pulses applied.

In a stepper motor, an internal rotor containing permanent magnets is controlled by a set of stationary electromagnets that are switched electronically. Hence, it is a cross between a DC electric motor and a solenoid.

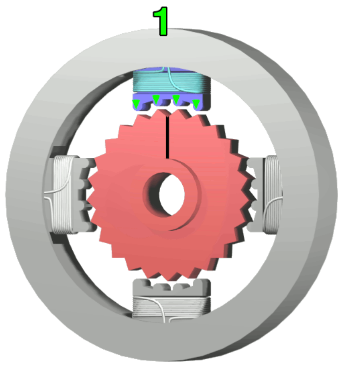



Figure 15. The top electromagnet (1) is charged, attracting the topmost four teeth of a sprocket.

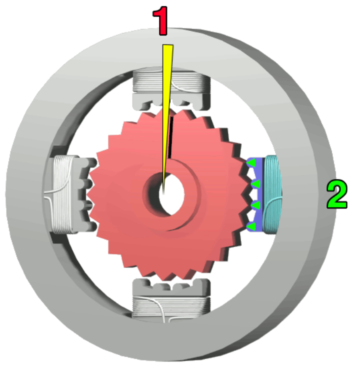



Figure 16. The top electromagnet (1) is turned off, and the right electromagnet (2) is charged, pulling the nearest four teeth to the right. This results in a rotation of 3.6°.

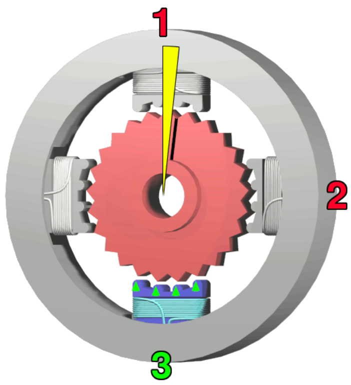



Figure 17. The bottom electromagnet (3) is charged; another 3.6° rotation occurs.

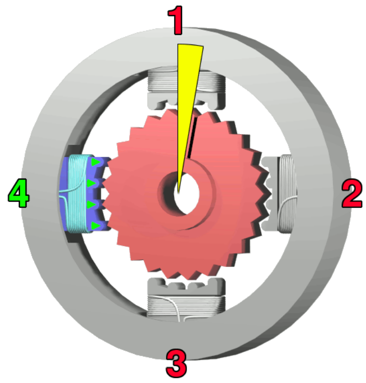



Figure 18. The left electromagnet (4) is enabled, rotating again by 3.6°. When the top electromagnet (1) is again charged, the teeth in the sprocket will have rotated by one tooth position; since there are 25 teeth, it will take 100 steps to make a full rotation.

Stepper motors have a fixed number of magnetic poles that determine the number of steps per revolution. Most common stepper motors have 200 full steps/revolution, meaning it takes 200 full steps to turn one revolution. Advanced stepper motor controllers can utilize pulse-width modulation to perform microsteps, achieving higher position resolution and smoother operation. Some microstepping controllers can increase the step resolution from 200 steps/rev to 50,000 microsteps/rev.

Stepper motors are rated by the torque they produce. A unique feature of steppers is their ability to provide position holding torque while not in motion. To achieve full rated torque, the coils in a stepper motor must reach their full rated current during each step. Stepper motor drivers must employ current regulating circuits to realize this. The voltage rating (if there is one) is almost meaningless.

Computer controlled stepper motors are one of the most versatile forms of positioning systems, particularly when digitally controlled as part of a servo system. Stepper motors are used in floppy disk drives, flatbed scanners, printers, plotters and many more devices. Note that hard drives no longer use stepper motors, instead utilising a voice coil and servo feedback for head positioning.

### 4.3 Basic wiring diagram

The following motor is a two phases motor, and it is sometimes called unipolar. The two-phase coils are center-tapped and in this case the center-taps are connected to ground.

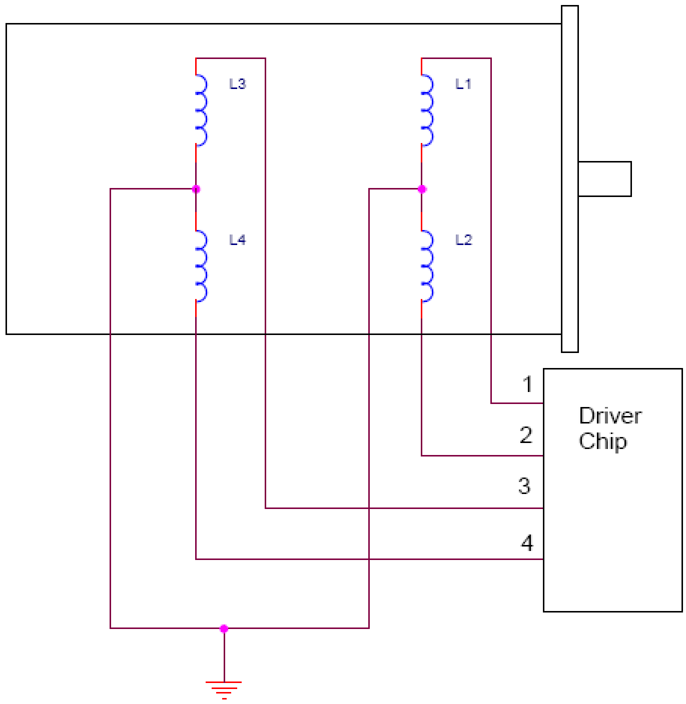



Figure 19. Basic wiring diagram of a stepper motor.

## 4.4 Stepper motor advantages

- Low cost
- Ruggedness
- Simplicity in construction
- No maintenance
- The rotation angle of the motor is proportional to the input pulse
- The motor has full torque at standstill (if the windings are energized)
- Precise positioning and repeatability of movement since good steppes motors have an accuracy of 3 - 5% of a step and this error is non cumulative from one step to the next
- Excellent response to starting/stopping/reversing
- Very reliable since there are no contact brushes in the motor. Therefore the life of the motor is simply dependant on the life of the bearing
- The motors response to digital input pulses provides open-loop control, making the motor simpler and less costly to control
- It is possible to achieve very low speed synchronous rotation with a load that is directly coupled to the shaft

- A wide range of rotational speeds can be realized as the speed is proportional to the frequency of the input pulses

## 4.5 Stepper motor disadvantages

- Resonance effects and relatively long settling times
- Rough performance at low speed unless a microstep drive is used
- Liability to undetected position loss as a result of operating open-loop
- They consume current regardless of load conditions and therefore tend to run hot
- Losses at speed are relatively high and can cause excessive heating, and they are frequently noisy (especially at high speeds)
- They can exhibit lag-lead oscillation, which is difficult to damp. There is a limit to their available size, and positioning accuracy relies on the mechanics. Many of these drawbacks can be overcome by the use of a closed-loop control scheme

## 4.6 Stepper motor types

There are three basic stepper motor types. They are: Variable-reluctance, Permanent-magnet and Hybrid. They differ in terms of construction based on the use of permanent magnets and/or iron rotors with laminated steel stators.

### 4.6.1 Variable Reluctance (VR)

This type of stepper motor has been around for a long time. It is probably the easiest to understand from a structural point of view. This type of motor consists of a soft iron multi-toothed rotor and a wound stator. When the stator windings are energized with DC current the poles become magnetized. Rotation occurs when the rotor teeth are attracted to the energized stator poles.

### 4.6.2 Permanent Magnet (PM)

Often referred to as a “tin can” or “canstock” motor the permanent magnet step motor is a low cost and low resolution type motor with typical step angles of 7.5º to 15º (48-24 steps/revolution). Permanent Magnet motors, as the name implies, have permanent magnets added to the motor structure. The rotor no longer has teeth as with the VR motor. Instead the rotor is magnetized with alternating north and south poles situated in a straight line parallel to the rotor shaft. These magnetized rotor poles provide an increased magnetic flux intensity and because of this the PM motor exhibits improved torque characteristics when compared with the VR type.

### 4.6.3 Hybrid (HB)

The hybrid stepper motor is more expensive than the PM stepper motor but provides better performance with respect to step resolution, torque and speed. Typical step angles for the HB stepper motor range from 3.6º to 0.9º (100-400 steps per revolution). The hybrid stepper motor combines the best features of both the PM and VR type stepper motors. The rotor is multi-toothed like the VR motor and contains an axially magnetized concentric magnet around its shaft. The teeth on the rotor provide an even better path which helps guide the magnetic flux to preferred locations in the airgap. This further increases the detent, holding and dynamic torque characteristics of the motor when compared with both the VR and PM types.

The two most commonly used types of stepper motors are the permanent magnet and the hybrid types. If a designer is not sure which type will best fit his applications requirements he should first evaluate the PM type as it is normally several times less expensive. If not then the hybrid motor may be right choice.

There also exist some especial stepper motor designs. One is the disc magnet motor. Here the rotor is designed as a disc with rare earth magnet. This motor has some advantages such as very low inertia and an optimized magnetic flow path with no coupling between the two stator windings. These qualities are essential in some applications.

## 4.7 Stepping modes

The following are the most common driving modes:

- Wave Drive (1 phase on)
- Full Step Drive (2 phases on)
- Half Step Drive (1 & 2 phases on)
- Microstepping (continuously varying motor currents)

For the following discussions refer to the Figure 20.

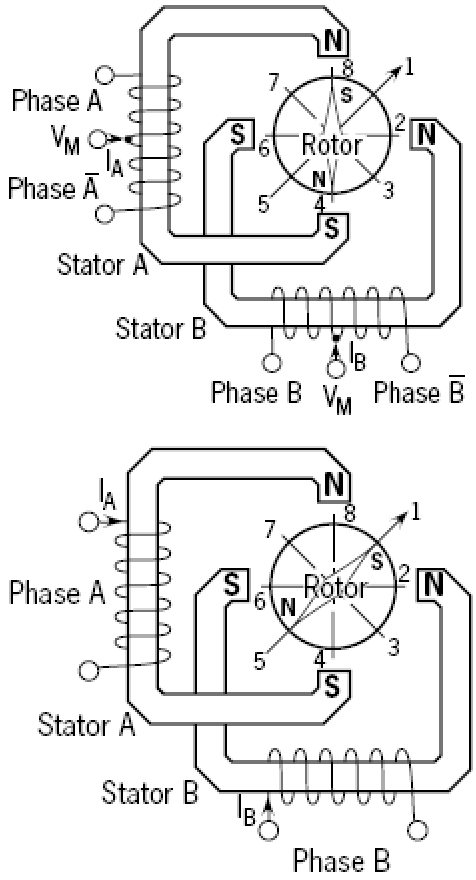



Figure 20. Unipolar and bipolar wound stepper motors.

### 4.7.1 Wave Drive

In Wave Drive only one winding is energized at any time given. The stator is energized according to the sequence A→B→$\overline{A}\rightarrow\overline{B}$ and the rotor steps from position 8→2→4→6. For unipolar and bipolar wound motors with the same winding parameters this excitation mode would result in the same mechanical position. The disadvantage of this drive mode is that the unipolar wound motor you are only using 25% and in the bipolar motor only 50% of the total motor winding at any given time. This means that you are not getting the maximum torque output from the motor.

### 4.7.2 Full Step Drive

In Full Step Drive you are energizing two phases at any given time. The stator is energized according to the sequence AB→$\overline{A}$B→$\overline{A}\,\overline{B}$→A$\overline{B}$ and the rotor steps from position

1→3→5→7. Full step mode results in the same angular movement as 1 phase on drive but the mechanical position is offset by one half of a full step. The torque output of the unipolar wound motor is lower than the bipolar motor (for motors with the same winding parameters) since the unipolar motor uses only 50% of the available winding while the bipolar motor uses the entire winding.

### 4.7.3 Half Step Drive

Half Step Drive combines both wave and full step (1&2 phases on) drive modes. Every second step only one phase is energized according to the sequence AB→B→$\overline{A}$B→$\overline{A}$→$\overline{A}\,\overline{B}$→$\overline{B}$→A$\overline{B}$→A and the rotor steps from 1→2→3→4→5→6→7→8. This result in angular movements that are half of those in 1 or 2 phases on drive modes. Half stepping can reduce a phenomena referred to as resonance which can be experienced in 1 or 2 phases on drive modes. The excitation sequences for the above drive modes are summarized in Figure 21.

| | Wave Drive | | | | Normal full step | | | | Half-step drive | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Phase | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| A | • | | | | • | | | • | • | | | | | | • | • |
| B | | • | | | • | • | | | • | • | • | | | | | |
| $\overline{A}$ | | | • | | | • | • | | | | • | • | • | | | |
| $\overline{B}$ | | | | • | | | • | • | | | | | | • | • | • |

Figure 21. Excitation sequences for different drive modes.

### 4.7.4 Microstepping Drive

In Microstepping Drive the currents in the windings are continuously varying to be able to break up one full step into many smaller discrete steps.

Microstepping serves two purposes. First, it allows a stepping motor to stop and hold a position between the full or half-step positions, second, it largely eliminates the jerky character of low speed stepping motor operation and the noise at intermediate speeds, and third, it reduces problems with resonance.

Although some microstepping controllers offer hundreds of intermediate positions between steps, it is worth noting that microstepping does not generally offer great precision, both because of linearity problems and because of the effects of static friction.

### 4.8 When to use a Stepper Motor

A stepper motor can be a good choice whenever controlled movement is required. They can be used to advantage in applications where you need to control rotation angle, speed, position and synchronism. Because of the inherent advantages listed previously, stepper motors have found their place in many different applications.

For some applications, there is a choice between using servomotors and stepping motors. Both types of motors offer similar opportunities for precise positioning, but they differ in a number of ways. Servomotors require analog feedback control systems of some type. Typically, this involves a potentiometer to provide feedback about the rotor position, and some mix of circuitry to drive a current through the motor inversely proportional to the difference between the desired position and the current position.

In making a choice between steppers and servos, a number of issues must be considered; which of these will matter depends on the application. For example, the repeatability of positioning done with a stepping motor depends on the geometry of the motor rotor, while the repeatability of positioning done with a servomotor generally depends on the stability of the potentiometer and other analog components in the feedback circuit.

Stepping motors can be used in simple open-loop control systems; these are generally adequate for systems that operate at low accelerations with static loads, but closed loop control may be essential for high accelerations, particularly if they involve variable loads. If a stepper in an open-loop control system is overtorqued, all knowledge of rotor position is lost and the system must be reinitialized; servomotors are not subject to this problem.

### 4.9 Applications

Stepper motors can be found almost anywhere. Most of us use them everyday without even realizing it. For instance, steppers power "analog" wristwatches (which are actually digital), disc drives, printers, robots, cash points, machine tools, CD players, profile cutters, plotters and much more. Unlike other electric motors they do not simply rotate smoothly when switched on. Every revolution is divided into a number of steps (typically 200) and the motor must be sent a separate signal for each step. It can only take one step at a time and each step is the same size, thus step motors may be considered a digital device. See below for more applications:

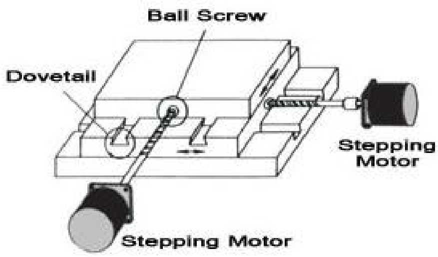



Figure 22. X-Y table.

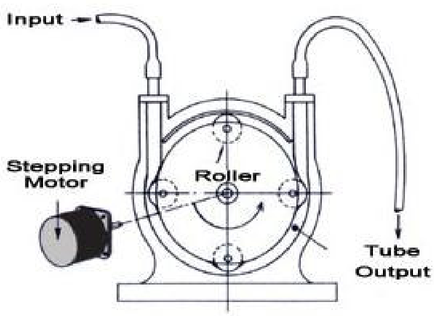



Figure 23. Constant flow pump.

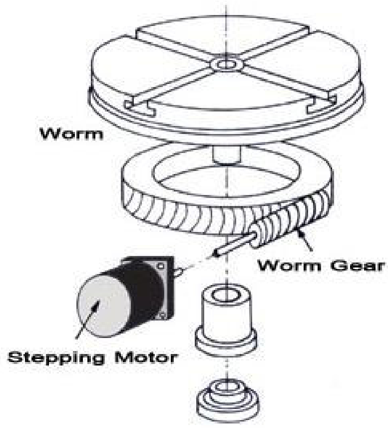



Figure 24. Index table.

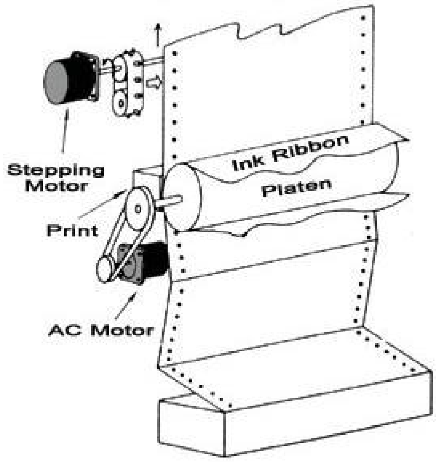



Figure 25. Printer.

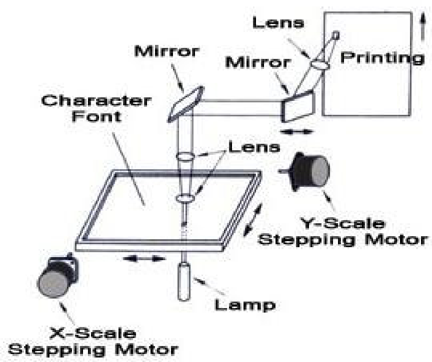



Figure 26. Photo typesetting.

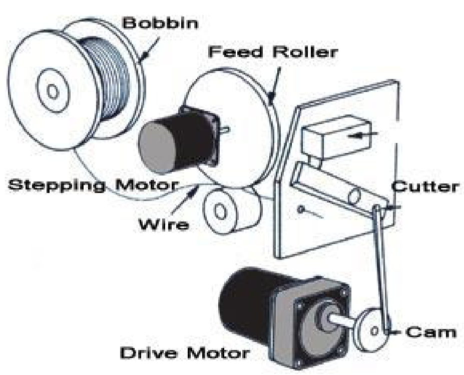



Figure 27. Wire cutter.

# 5 PARALLEL PORT

## 5.1 Defining the Port

In the computer world, a port is a set of signal lines that the microprocessor, or CPU, uses to exchange data with other components. Typical uses for ports are communicating with printers, modems, keyboards, and displays, or just about any component or device except system memory. Most computer ports are digital, where each signal, or bit, is 0 or 1. A parallel port transfers multiple bits at once, while a serial port transfers a bit at a time (though it may transfer in both directions at once).

## 5.2 Parallel Port basics

The original IBM-PC's Parallel Printer Port has a total of 12 digital outputs and 5 digital inputs accessed via 3 consecutive 8-bit ports in the processor's I/O space.

- 8 output pins accessed via the DATA Port
- 5 input pins (one inverted) accessed via the STATUS Port
- 4 output pins (three inverted) accessed via the CONTROL Port
- The remaining 8 pins are grounded

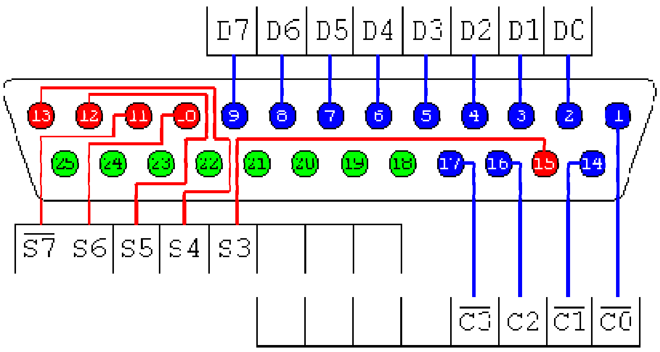



Figure 28. 25-way Female D-Type Connector.

## 5.3 Parallel Port Background

Parallel ports were originally developed by IBM as a way to connect a printer to your PC. When IBM was in the process of designing the PC, the company wanted the computer to work with printers offered by Centronics, a top printer manufacturer at the time. IBM decided not to use the same port interface on the computer that Centronics used on the printer.

Instead, IBM engineers coupled a 25-pin connector, DB-25, with a 36-pin Centronics connector to create a special cable to connect the printer to the computer. Other printer manufacturers ended up adopting the Centronics interface, making this strange hybrid cable an unlikely de facto standard.

When a PC sends data to a printer or other device using a parallel port, it sends 8 bits of data (1 byte) at a time. These 8 bits are transmitted parallel to each other, as opposed to the same eight bits being transmitted serially (all in a single row) through a serial port. The standard parallel port is capable of sending 50 to 100 kilobytes of data per second.

Let's take a closer look at what each pin does when used with a printer:

- Pin 1 carries the strobe signal. It maintains a level of between 2.8 and 5 volts, but drops below 0.5 volts whenever the computer sends a byte of data. This drop in voltage tells the printer that data is being sent.
- Pins 2 through 9 are used to carry data. To indicate that a bit has a value of 1, a charge of 5 volts is sent through the correct pin. No charge on a pin indicates a value of 0. This is a simple but highly effective way to transmit digital information over an analog cable in real-time.
- Pin 10 sends the acknowledge signal from the printer to the computer. Like Pin 1, it maintains a charge and drops the voltage below 0.5 volts to let the computer know that the data was received.
- If the printer is busy, it will charge Pin 11. Then, it will drop the voltage below 0.5 volts to let the computer know it is ready to receive more data.
- The printer lets the computer know if it is out of paper by sending a charge on Pin 12.
- As long as the computer is receiving a charge on Pin 13, it knows that the device is online.

- The computer sends an auto feed signal to the printer through Pin 14 using a 5-volt charge.

- If the printer has any problems, it drops the voltage to less than 0.5 volts on Pin 15 to let the computer know that there is an error.

- Whenever a new print job is ready, the computer drops the charge on Pin 16 to initialize the printer.

- Pin 17 is used by the computer to remotely take the printer offline. This is accomplished by sending a charge to the printer and maintaining it as long as you want the printer offline.

- Pins 18-25 are grounds and are used as a reference signal for the low (below 0.5 volts) charge.

| DB 25 | | Centronics 36 | |
|---|---|---|---|
| Pin | Signal | Pin | Signal |
| 1 | Strobe | 1 | Strobe |
| 2 | data0 | 2 | data0 |
| 3 | data1 | 3 | data1 |
| 4 | data2 | 4 | data2 |
| 5 | data3 | 5 | data3 |
| 6 | data4 | 6 | data4 |
| 7 | data5 | 7 | data5 |
| 8 | data6 | 8 | data6 |
| 9 | data7 | 9 | data7 |
| 10 | Acknowledge | 10 | Acknowledge |
| 11 | Busy | 11 | Busy |
| 12 | Paper End | 12 | Paper End |
| 13 | Select | 13 | Select |
| 14 | Auto Feed | 14 | Auto Feed |
| 15 | Error | 15 | Error |
| 16 | Init | 16 | Init |
| 17 | Select In | 17 | Select In |
| 18 | GND | 18 | GND |
| 19 | GND | 19 | GND |
| 20 | GND | 20 | GND |
| 21 | GND | 21 | GND |
| 22 | GND | 22 | GND |
| 23 | GND | 23 | GND |
| 24 | GND | 24 | GND |
| 25 | GND | 25 | GND |
| | | 26 | GND |
| | | 27 | GND |
| | | 28 | GND |
| | | 29 | GND |
| | | 30 | GND |
| | | 31 | Init |
| | | 32 | Error |
| | | 33 | Ground |
| | | 34 | NC |
| | | 35 | NC |
| | | 36 | Select In |

Table 3. DB-25 vs. 36-pin Centronics.

Notice how the first 25 pins on the Centronics end match up with the pins of the first connector. With each byte the parallel port sends out, a handshaking signal is also sent so that the printer can latch the byte.

### 5.4 SPP

The original specification for parallel ports was unidirectional, meaning that data only travelled in one direction for each pin. With the introduction of the PS/2 in 1987, IBM offered a new bidirectional parallel port design. This mode is commonly known as Standard Parallel Port (SPP) and has completely replaced the original design. Bidirectional communication allows each device to receive data as well as transmit it. Many devices use the eight pins (2 through 9) originally designated for data. Using the same eight pins limits communication to half-duplex, meaning that information can only travel in one direction at a time. But pins 18 through 25, originally just used as grounds, can be used as data pins also. This allows for full-duplex (both directions at the same time) communication.

### 5.5 EPP

Enhanced Parallel Port (EPP) was created by Intel, Xircom and Zenith in 1991. EPP allows for much more data, 500 kilobytes to 2 megabytes, to be transferred each second. It was targeted specifically for non-printer devices that would attach to the parallel port, particularly storage devices that needed the highest possible transfer rate.

| EPP | | | | | |
|---|---|---|---|---|---|
| Pin | EPP Signal | Pin | EPP Signal | Pin | EPP Signal |
| 1 | Write | 10 | Interrupt | 19 | Ground |
| 2 | Data 0 | 11 | Wait | 20 | Ground |
| 3 | Data 1 | 12 | Spare | 21 | Ground |
| 4 | Data 2 | 13 | Spare | 22 | Ground |
| 5 | Data 3 | 14 | Data Strobe | 23 | Ground |
| 6 | Data 4 | 15 | Spare | 24 | Ground |
| 7 | Data 5 | 16 | Reset | 25 | Ground |
| 8 | Data 6 | 17 | Address Strobe | | |
| 9 | Data 7 | 18 | Ground | | |

Table 4. Enhanced Parallel Port.

## 5.6 ECP

Close on the heels of the introduction of EPP, Microsoft and Hewlett Packard jointly announced a specification called Extended Capabilities Port (ECP) in 1992. While EPP was geared toward other devices, ECP was designed to provide improved speed and functionality for printers.

| ECP | | | | | |
|---|---|---|---|---|---|
| Pin | ECP Signal | Pin | ECP Signal | Pin | ECP Signal |
| 1 | HostCLK | 10 | PeriphCLK | 19 | Ground |
| 2 | Data 0 | 11 | PeriphAck | 20 | Ground |
| 3 | Data 1 | 12 | nAckReverse | 21 | Ground |
| 4 | Data 2 | 13 | X-Flag | 22 | Ground |
| 5 | Data 3 | 14 | Host Ack | 23 | Ground |
| 6 | Data 4 | 15 | PeriphRequest | 24 | Ground |
| 7 | Data 5 | 16 | nReverseRequest | 25 | Ground |
| 8 | Data 6 | 17 | 1284 Active | | |
| 9 | Data 7 | 18 | Ground | | |

Table 5. Extended Capabilities Port.

## 5.7 IEEE 1284

In 1994, the IEEE 1284 standard was released. It included the two specifications for parallel port devices, EPP and ECP. In order for them to work, both the operating system and the device must support the required specification. This is seldom a problem today since most computers support SPP, ECP and EPP and will detect which mode needs to be used, depending on the attached device. If you need to manually select a mode, you can do so through the BIOS on most computers.

# 6 COMPONENTS

All the IC's used in the board construction are 4000 series devices except the stepper motor driver. The 4000 series is the general classification used to refer to the industry standard integrated circuits which implement a variety of logic functions using CMOS technology. They were created in the 1960s as a lower power and more versatile alternative to the 7400 series of TTL logic chips. Almost all IC manufacturers have fabricated this series in part or whole over the years.

Initially, the 4000 series was slower than the popular 7400 TTL chips, but had the advantage of much lower power consumption, the ability to operate over a much wider range of supply voltages, and simpler circuit design due to the vastly increased fanout.

## 6.1 L293D

The SGS/Thomson L293 is an integrated circuit motor driver and in 16-pin dip package. The L293D contains two H-bridges for driving small DC motors. It can also be used to drive stepper motors because stepper motors are, in fact, two (or more) coils being driven in a sequence, backwards and forwards. One L293D can, in theory, drive one bi-polar 2 phase stepper motor, if you supply the correct sequence.

The L293D chip has 16 pins. Here is how each of the pins should be connected:

- Pin 1, 9: Enable pins. Hook them together and you can either keep them high and run the motor all the time, or you can control them with you own controller (e.g. 68HC11).
- Pin 3, 6, 11, 14: Here is where you plug in the two coils. To tell which wires correspond to each coil, you can use a multimeter to measure the resistance between the wires. The wires correspond to the same coil has a much lower resistance than wires correspond to different coils. (This method only applies to bipolar stepper motors. For unipolar stepper motors, you have to refer to the spec. sheet to tell which wires correspond to each coil.) You can then get one coil hooked up to pin 3, 6 and another one hooked up to pin 11, 14.
- Pin 4, 5, 12, 13: Gets hooked to ground.
- Pin 8: Motor voltage, for the motors we are using, it is 12V.

- Pin 16: +5V. It is the power supply of the chip and it's a good idea to keep this power supply separate from your motor power.
- Pin 2, 7, 10, 15: Control signals. Here is where you supply the pulse sequence. The following is how you pulse them for a single-cycle (to move the motor in the opposite direction, just reverse the steps. i.e. from step 4 to step1):

| | Coil 1a | Coil 2a | Coil 1b | Coil 2b |
|---|---|---|---|---|
| Step 1 | High | High | Low | Low |
| Step 2 | Low | High | High | Low |
| Step 3 | Low | Low | High | High |
| Step 4 | High | Low | Low | High |

Table 6. Pulse sequence.

### 6.2 HEF4027B

The HEF4027 is a dual JK flip-flop with set and clear. Data is accepted when CP is LOW, and transferred to the output on the positive-going edge of the clock.

| INPUTS | | | | | OUTPUTS | |
|---|---|---|---|---|---|---|
| $S_D$ | $C_D$ | CP | J | K | $O_{n+1}$ | $\overline{O}_{n+1}$ |
| L | L | ↑ | L | L | no change | |
| L | L | ↑ | H | L | H | L |
| L | L | ↑ | L | H | L | H |
| L | L | ↑ | H | H | $\overline{O}_n$ | $O_n$ |

Table 7. Function table.

## 6.3 HEF4030B

The HEF4030B provides the positive quadruple exclusive-OR function.

| $I_1$ | $I_2$ | $O_1$ |
|---|---|---|
| L | L | L |
| H | L | H |
| L | H | H |
| H | H | L |

Table 8. Truth table.

## 6.4 HCF4050

The HCF4050 (intermediate temperature range) is a monolithic integrated circuit available in 16-lead dual in-line plastic or ceramic package and plastic micro package. It is a non-inverting hex buffer and feature logic-level conversion using only one supply voltage (VDD). The input-signal high level (VIH) can exceed the VDD supply voltage when this device is used for logic level conversions.

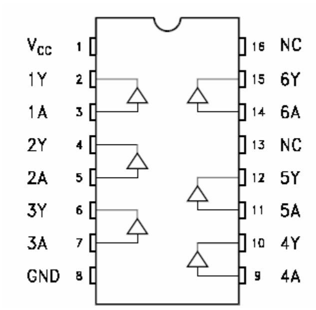



Figure 29. HCF4050 pin connection.

## 6.5 HCF4049

The HCF4049 is exactly the same than the HCF4050 with the difference that this device is an inverting hex buffer.

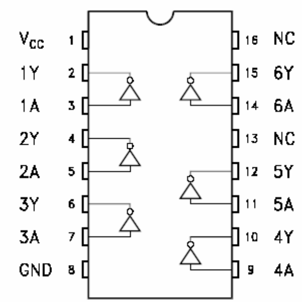



Figure 30. HCF4049 pin connection.

## 6.6 Stepper Motor

Some chapters ago we have explain all about stepper motor. The stepper motors characteristics used in the MiniMover-5 are below:

- 4 phase permanent magnet stepper motor
- 6 lead
- 7.5 degrees per step
- 48 steps per revolution
- 0.33A per phase
- Coil resistance 36 ohms per phase

Figure 31. A stepper motor.

# 7 THE BOARD

## 7.1 Choosing the interface

Before starting this project, the main purpose was to build a new control board to control the manipulator from a PC.

Last summer, the MRC (Mechatronics Research Centre) bought a Cypress Semiconductor EZ-USB Development Board, in other words a board that can connect any device to the computer via USB. At first it seemed a good idea controlling the robot with that board, but after researched it and tested it we realised that it maybe was not the best solution due to its complexity. The Cypress Company says that "There is a lot going on 'under the hood' of a USB device" and "the board's outward simplicity hides internal complexity".

Figure 32. EZ-USB Development Board.

In my opinion, in electronics' world stuff has to be as simple as possible. That is why we decided to look for other possibilities. We thought about the parallel port, and after researched it, we realised it was the best choice, due to its simplicity, its little room, and because we could control the whole robot with just one parallel port. So we were completely sure about it.

## 7.2 Designing the circuit

The first step before building the board is design the circuit. Our circuit has to control the 6 stepper motors of the robot. But before designing this circuit, we have been trying to control just one of them.

First of all, we tried to use the driver SAA1027. The circuit was not very complicated; it had not too many components. This is a very interesting and important point because the more components you have the easier is that it does not work.

When we finished the circuit design and we were prepared to order all the components, we realised that this driver was an old-fashioned one and it was not available in any place. As a consequence all the work we had done and all the time we had invested until that moment was in vain. So we had to start again.

Finally we found another driver for stepper motors, the L293D. We checked that it was in sale, and then we designed the circuit. First of all, we designed the circuit for one stepper motor, and when it worked then we designed the whole circuit.

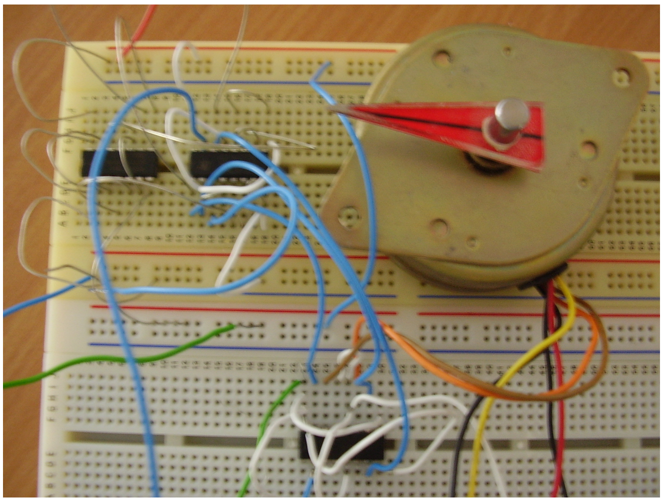


Figure 33. Circuit to control one stepper motor.

### 7.3 Circuit explanation

If you look carefully to the big circuit, you will notice that is composed of six smaller circuits, one for each stepper motor. In each “small” circuit that starts in the parallel port’s output we can distinguish different parts in order to be easily understood.

- The buffers
- The XOR gates
- The JK flip-flops
- The driver

The parallel port has 25 pins, which we use 20 pins. Seven of them are connected to ground; twelve are used as outputs and one as an input.

The buffers are a way to isolate the parallel port’s signals from the rest of the circuit. They enable high noise immunity and stable the parallel port’s output. Due to some inputs/ouputs are inverted we have used some inverted buffers and the others non-inverted.

In the XOR gates we have to pay attention to the fact there are only three changeable inputs: the input number 2 is the direction we choose through the parallel port, and inputs 8 and 9 depend on the flip-flop outputs.

In the JK flip-flops, the outputs change on the positive-going edge of the clock. The clock frequency is the motor step, and we send it through the parallel port. J and K inputs, which are connected together, come from the previous XOR gate. S and R inputs are connected to ground as it indicates the data sheet.

The driver L293 is situated between the JK flip-flops and the stepper motor; actually instead of the stepper motor there is a header that then connect with the stepper motor.

We have run all the logical devices on 5V and the motors on 12V to get some more torque.

We have also get the output of the micro switch back into the PC, again through the parallel port. We have connected it to 5V and we have placed a resistor of 100k to limit the intensity through the switch.

The table below reflects all the values the outputs in the circuit can take depending on the inputs:

| CLK | $Q1_{ant}$ | $Q2_{ant}$ | 1 | 2 | 8 | 9 | 5 | 6 | 12 | 13 | JK2 | Q2 | JK1 | Q1 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **L** | 0 | 0 | 1 | 1 | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 0 | 0 | 0 |
| **L→H** | 0 | 0 | 1 | 1 | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 0 | 0 |
| **H→L** | 0 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 |
| **L→H** | 0 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 1 |
| **H→L** | 1 | 0 | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 0 | 1 |
| **L→H** | 1 | 0 | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 1 | 1 | 0 | 0 | 1 |
| **H→L** | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 1 |
| **L→H** | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 0 |

Table 9. Values of the circuit.

### 7.4 Designing the schematic and the PCB

Designing the schematic and the PCB has been one of the most lasting tasks in this project. Actually it is not difficult if you have the tools and the software you need; but it was not in that way. Obtain the required software has not been easy. First we tried with the Eagle's Light version, but our circuit had too many components for it. We have tried several programs, but we had some troubles with all of them. Eventually, the software we have used is the Eagle Professional version.

In the schematic, in order to be easily understood, we have drawn each "small" circuit in one sheet, as well as the parallel port and the switch connections. So we have seven sheets in total.

Once you have already designed the schematic, next step is making the PCB. You have to be careful in the board's size and making it as small as you can. Our board's size is 120x135 mm. It was quite difficult to design because we have too many components. So to fit it in a small size we have had to make several vias.

# 8 CONCLUSION

## 8.1 Technical conclusion

We can say that nearly all the objectives proposed at the beginning of the project have been done although we have made some changes such as instead of controlling the robot via USB, we have control it using the parallel port. In its moment we consider, because of the reasons that are explained some chapters ago, it was the best solution.

I am a little bit disappointed not having built the board and test it and see with my own eyes that it really works. Eventually, they were some problems in the laboratory and we could not build it. But al least, all the hard work that is designing the board has been done. Whenever someone wants to build the board to control the MinjMover-5 just have to take this project and build it; as easy as that.

## 8.2 Personal conclusion

On a personal level, I have reached almost all my objectives. I have obviously improved my English, at least my spoken English. The first few days are quite hard speaking all day in a language which is not your mother language, and you think: “Oh my God! What have I done?” But then, little by little, you get used to it and even think in English! What you never get used to is the Welsh accent…

At first it is hard as well because you feel alone, you are alone actually! And moreover all is different: the language, the country, the people, the habits, the culture, the food… But once you have started to meet people all is easier. Then, little by little, you are getting used to it until one day you realise you are really used to all (or nearly)!

Referring to the project, firstly I thought I was going to work in a group with some more people. But I didn’t. I have had to work by my own. I have learned to learn by myself. I have learned to work by myself and autonomously. I have learned to be more independent. I have improved my skills in the electronics’ world as well.

Doing an exchange to a foreign country makes you grow as a person and makes you stronger. You meet a lot of people as well, and not only English people… It's so funny when two (or more) foreign people are speaking in English!

I'm sure I'll never forget this experience and all I have learned will be very useful in many aspects of my life.

Tania Lillo Holgueras

Industrial Technical Engineer speciality in Electronics

Newport, 12 January 2006

# 9 BIBLIOGRAPHY


ALTRONICS. SGS-Thomson L293D Data Sheet. (http://www.alltronics.com/download/1330.pdf, 5th October 2005)

ARRICK, R. The difference between Stepper motors, Servos and RC Servos. (http://www.robotics.com/motors.html, 8th November 2005)

AXELSON, J. Parallel Port Complete. (http://www.lvr.com/files/ppc1.pdf, 22nd November 2005)

AXELSON, J. Parallel Port Complete: programming, interfacing and using the PC's parallel printer port. Lakeview Research. 1996

AXELSON, J. USB Complete: everything you need to develop custom USB peripherals. Lakeview Research. 2001

CIPAGAUTA, A. And SALAZAR, J. Motores paso a paso. (http://www.gratisweb.com/industriasajltda/motores_paso_a_paso.html, 7th November 2005)

COLMENARES APITZ, J. Motores paso a paso. (http://www.monografias.com/trabajos17/motor-paso-a-paso/motor-paso-a-paso.shtml, 11th October 2005)

CYPRESS. CY7C646xx. (http://www.cypress.com/portal/server.pt?space=Communityage&controlSetCommunity&CommunityID=209&PageID=259&fid=13&rpn=CY7C646xx, 26th September 2005)

EDUCIPEDYA. Electricity machines. (http://users.pandora.be/educypedia/electronics/motorstep.htm, 4th October 2005)

ELECTRONICS LAB. Parallel Port Configuration. (http://www.geocities.com/nozomsite/parallel.htm, 8th November 2005)

ENGDAHL, T. Parallel Port. (http://www.epanorama.net/circuits/parallel_output.html, 22nd November 2005)

GONZALEZ GARCIA, E. Microcontrolador 16F84 (http://www.eis.uva.es/amuva/cybertaller/electronica/electronica.htm, 11th October 2005)

GOTTLIEB, I. Electric motors and control techniques. TAB Books. 1994.

HARRES, IAN. Stepper Motor Controller Connection Diagrams. (http://www.doc.ic.ac.uk/~ih/doc/stepper/control2/connect.html, 3rd November 2005)

HOW STUFF WORKS. How parallel port works. (http://computer.howstuffworks.com/parallel-port.htm, 22nd November 2005)

JONES, D. Control of stepping motors. (http://www.cs.uiowa.edu/%7Ejones/step/index.html#abstract, 8th November 2005)

KEIL. Technical Reference Manual. (http://www.keil.com/dd/docs/datashts/cypress/fx_trm.pdf, 26th September 2005)

MARTIN, D. PIC16F84. (http://www.x-robotics.com/ucpic.htm, 11th October 2005)

MONTEJO RAEZ, M.A. SAA 1027. (http://www.redeya.com/electronica/tutoriales/saa1027/saa1027.htm, 3rd November 2005)

MOR, I. Control de motores paso a paso con el SAA1027. (http://www.eupmt.es/cra/inform/info2.html, 7th November 2005)

NETMOTION. Motors. (http://www.netmotion.com/htm_files/adv_motors.htm#six, 8th November 2005)

STEIN, L. Parallel Port Background. (http://www.fapo.com/porthist.htm, 22nd November 2005)

REMIRO DOMINGUEZ, F. Motores Paso a Paso. (http://autric.com/Microbotica%20y%20Mecatronica/motores_paso_a_paso.htm, 6th October 2005)

ROBOTERWELT. Stepper Motor Driver IC SAA 1027. (http://www.roboterwelt.de/info/sheet/saa1027.pdf, 3rd November 2005)

USB-F, Inc. Universal Serial Bus. (http://www.usb.org, 25th September 2005)

WEBOPEDIA. USB. (http://www.webopedia.com/TERM/u/USB.html, 25th September 2005)

WIKIPEDIA. Stepper motor. (http://en.wikipedia.org/wiki/Stepper_motor, 8th November 2005)

WIKIPEDIA. USB. (http://es.wikipedia.org/wiki/USB, 25th September 2005)

# A APPENDIX. LAYOUTS AND SCHEMATICS

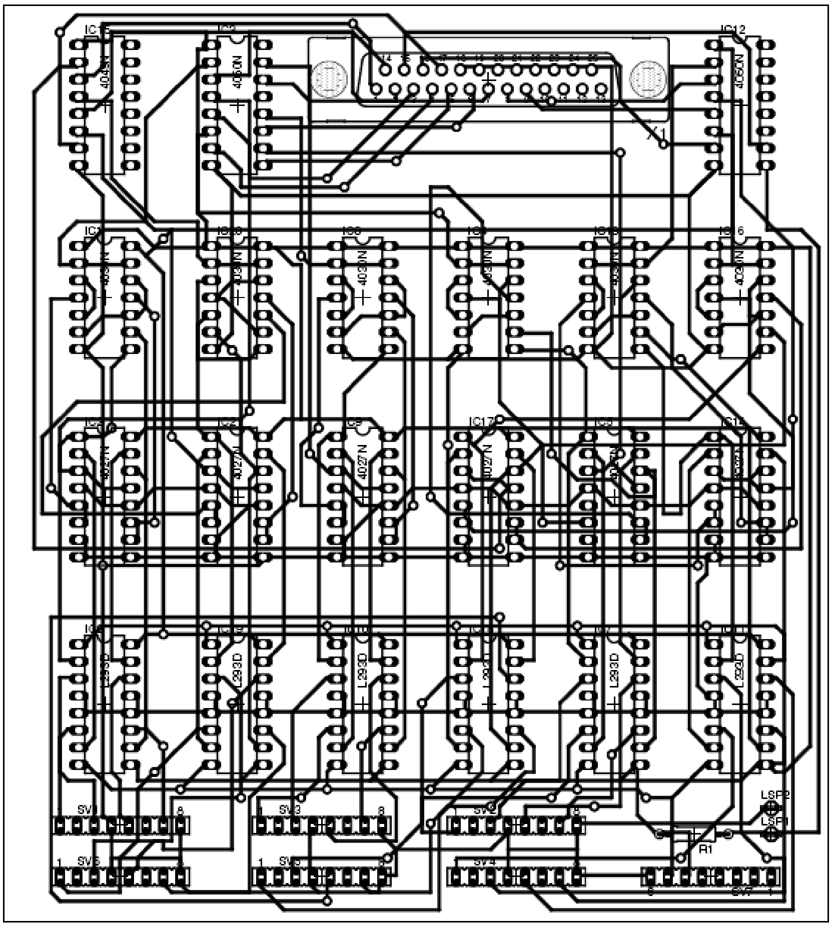


Figure A1. All connectivity.

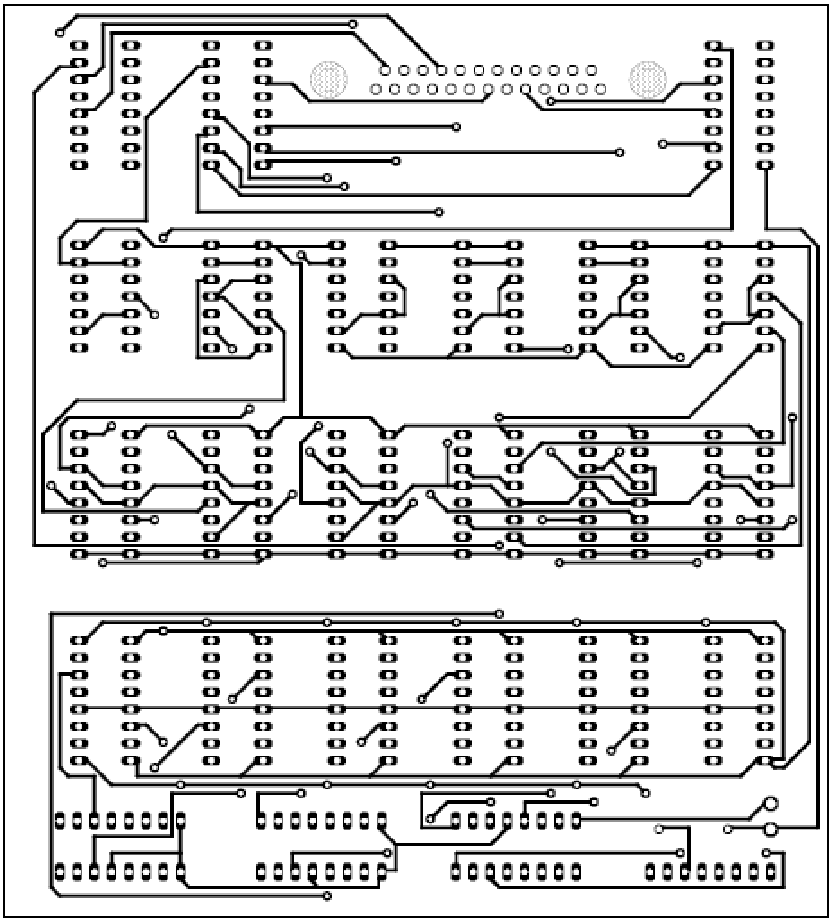


Figure A2. Bottom Layer.

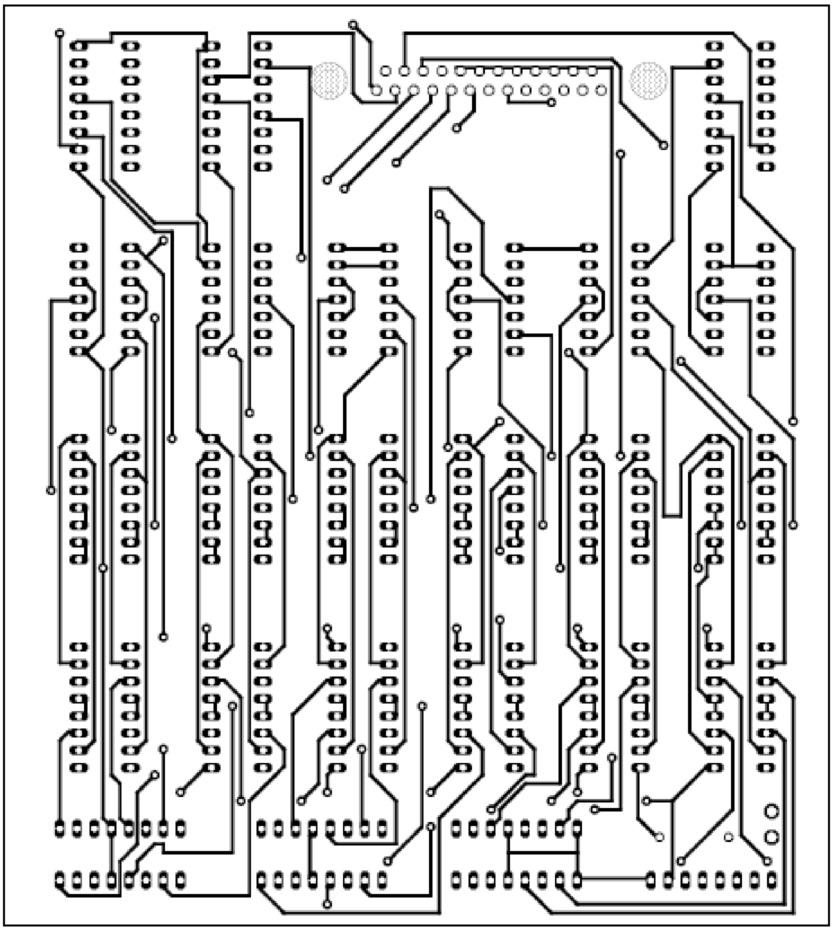


Figure A3. Top Layer.

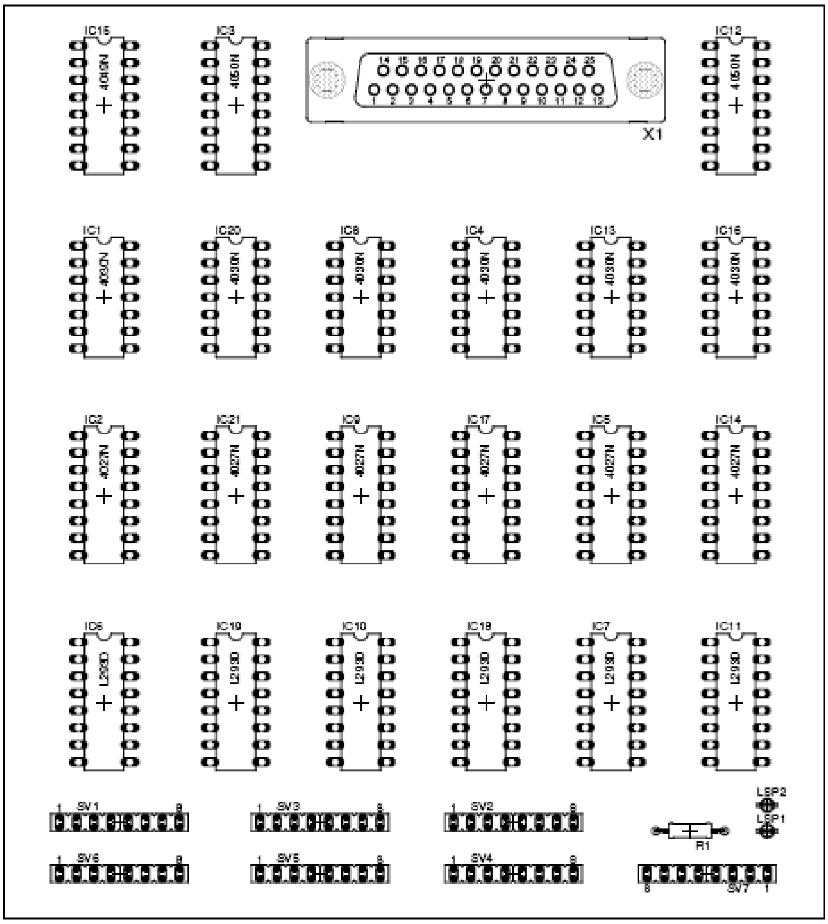
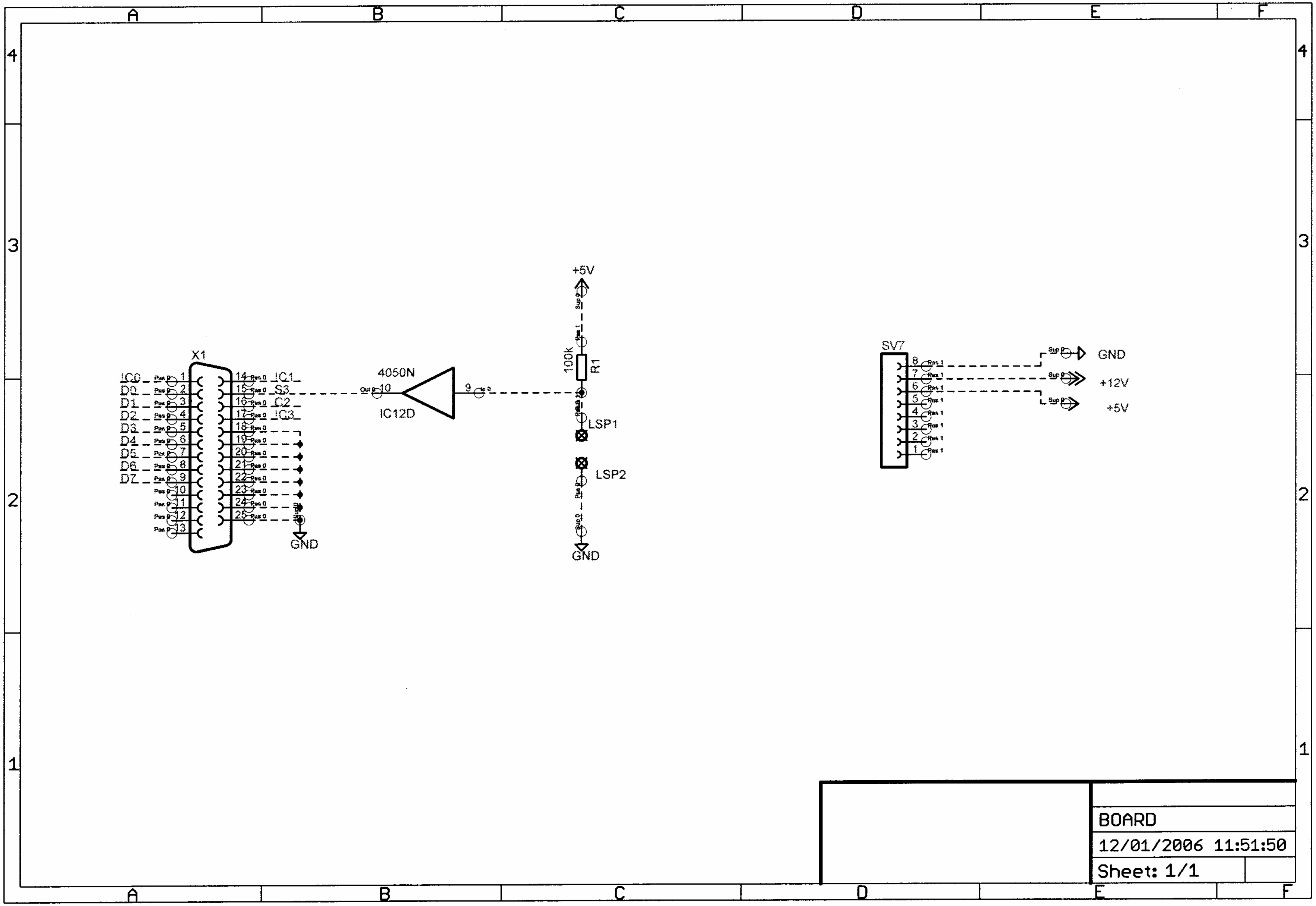



Figure A4. Components Layer.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IC0
D0
D1
D2
D3
D4
D5
D6
D7
IC1
S3
C2
IC3
GND
4050N
IC12D
+5V
100k
R1
LSP1
LSP2
GND
SV7
GND
+12V
+5V
BOARD
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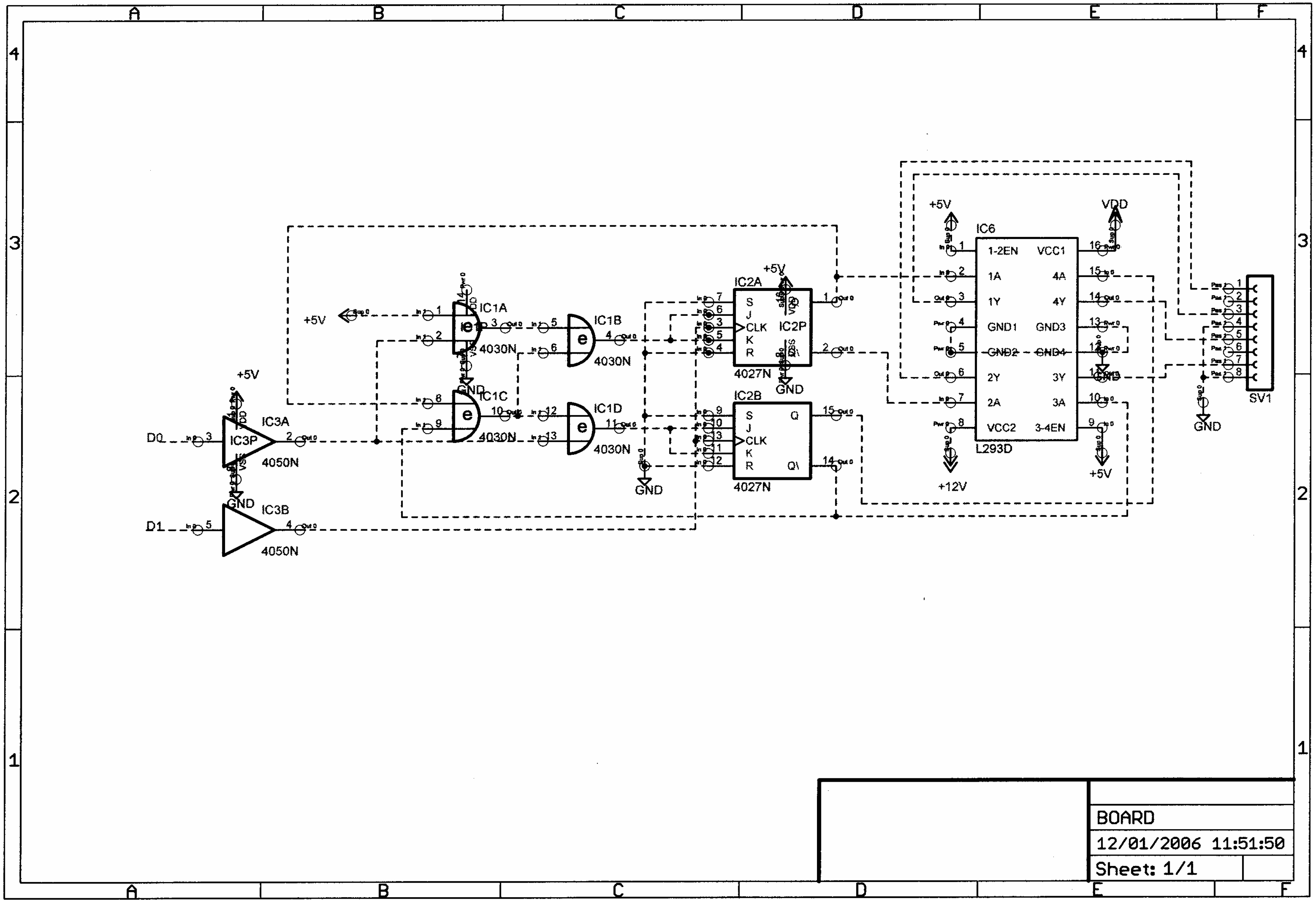
Sheet: 1/1



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D1
IC3A
IC3B
IC3P
4050N
VDD
VSS
+5V
GND
IC1A
IC1B
IC1C
IC1D
IC1P
4030N
IC2A
IC2B
IC2P
4027N
S
J
CLK
K
R
Q
Q\
IC6
L293D
1-2EN
1A
1Y
GND1
GND2
2Y
2A
VCC2
VCC1
4A
4Y
GND3
GND4
3Y
3A
3-4EN
+12V
SV1
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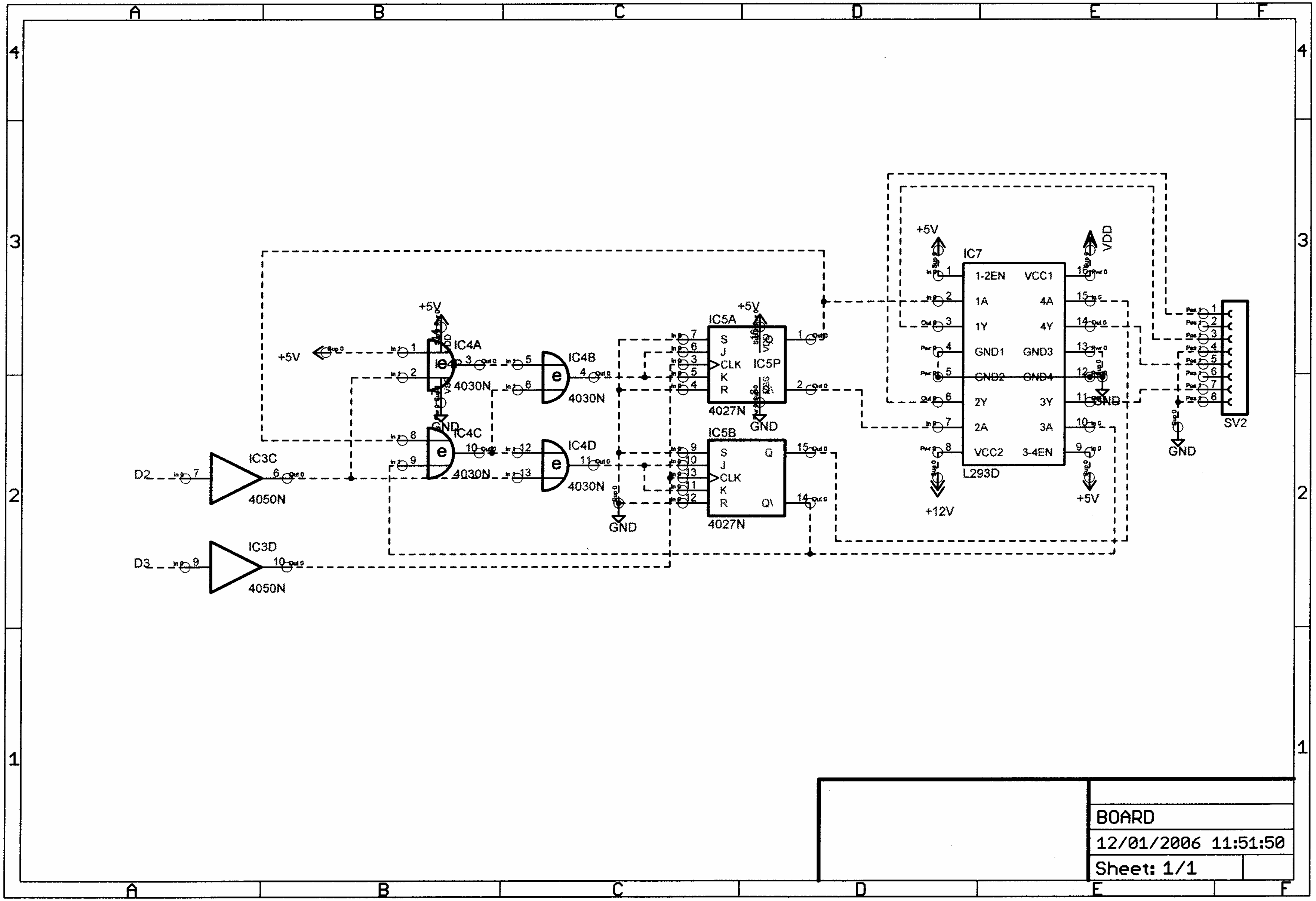
Sheet: 1/1



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4050N
IC3D
4050N
D2
D3
IC4A
IC4B
IC4C
IC4D
4030N
IC5A
IC5B
IC5P
4027N
S
J
CLK
K
R
Q
Q\
IC7
L293D
1-2EN
1A
1Y
GND1
GND2
2Y
2A
VCC2
VCC1
4A
4Y
GND3
GND4
3Y
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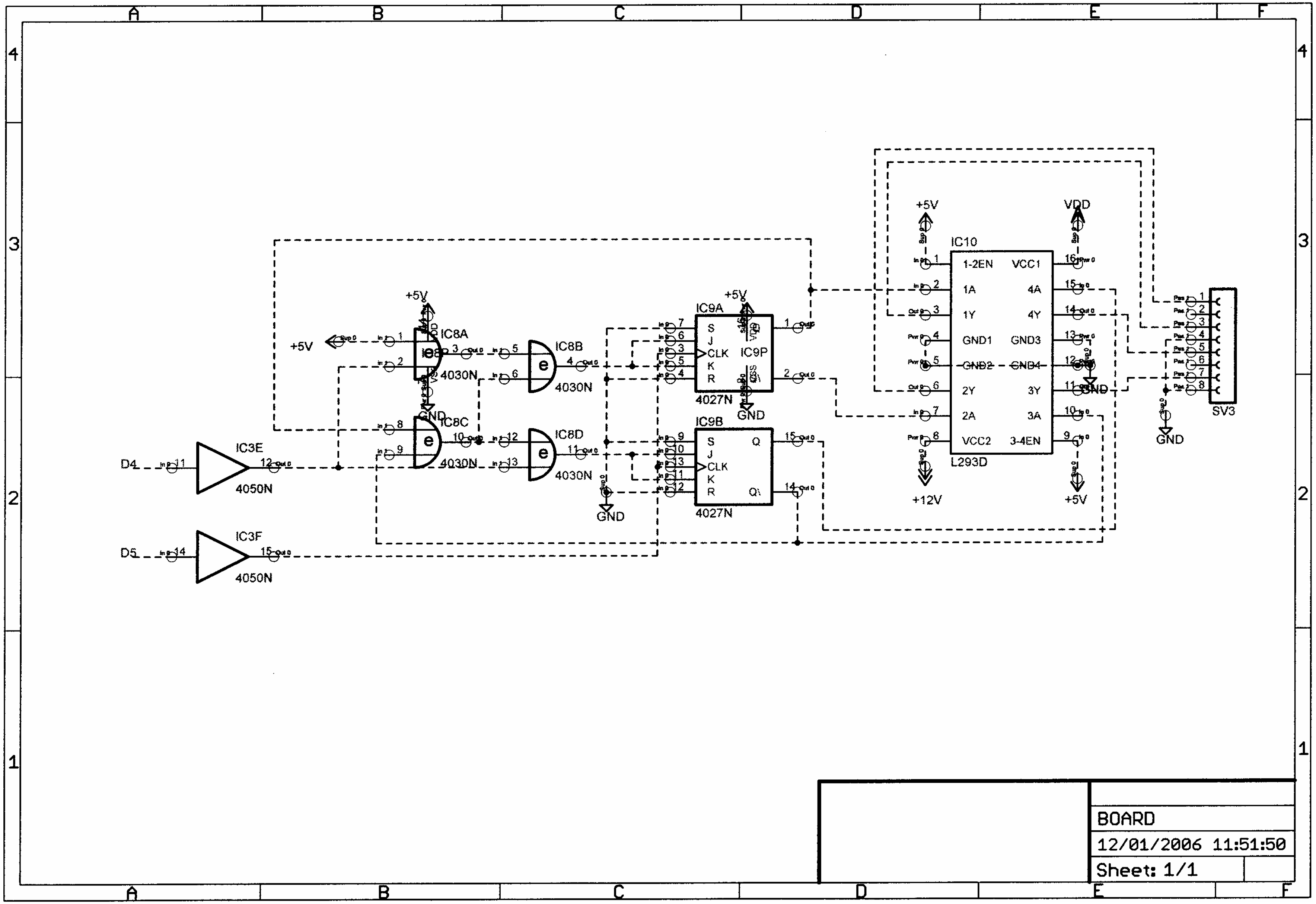

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D5
IC3E
IC3F
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IC8A
IC8B
IC8C
IC8D
4030N
IC9A
IC9B
IC9P
4027N
S
J
CLK
K
R
Q
Q\
IC10
L293D
1-2EN
1A
1Y
GND1
GND2
2Y
2A
VCC2
VCC1
4A
4Y
GND3
GND4
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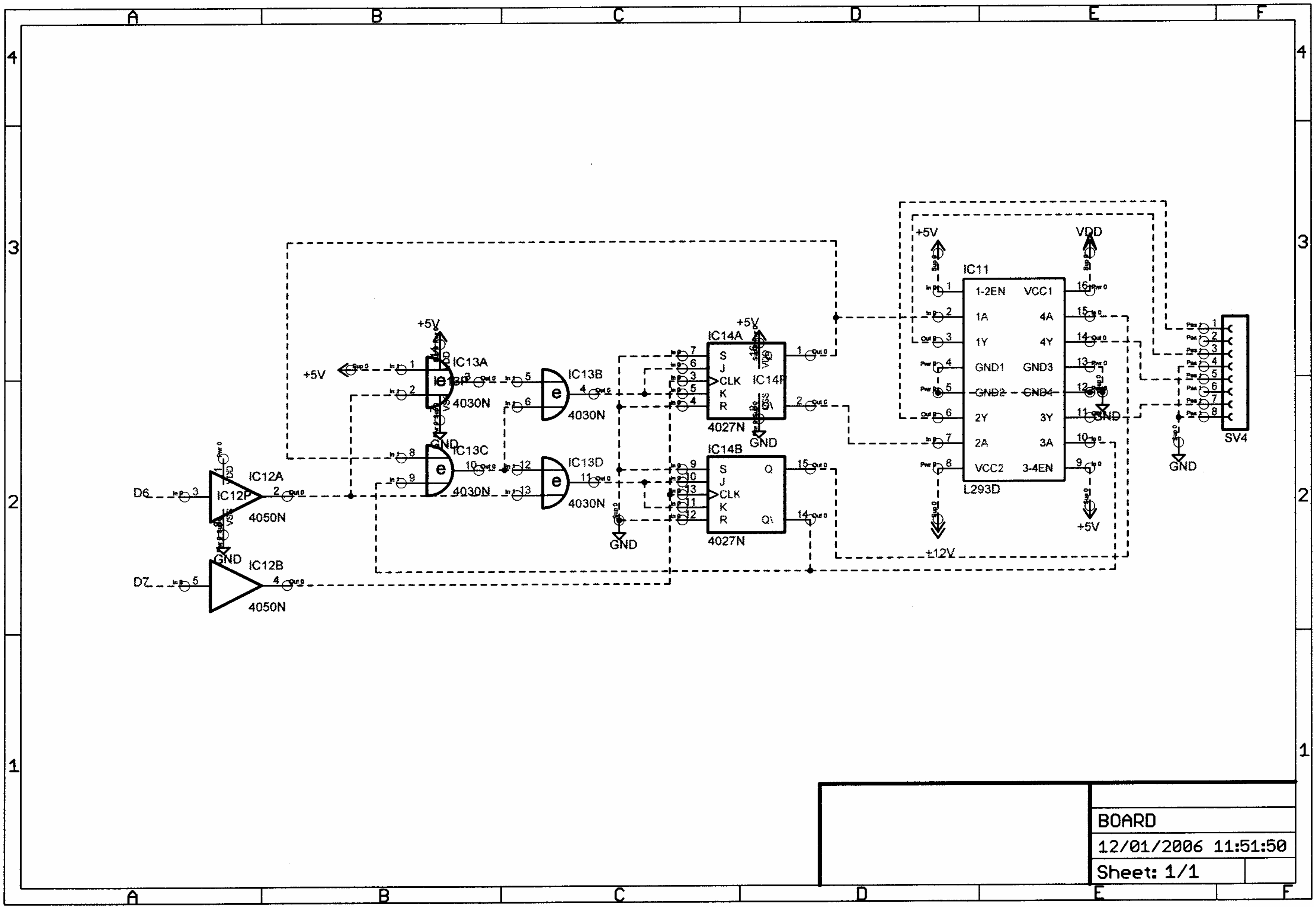
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IC13A
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IC13C
IC13D
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L293D
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VCC1
1A
4A
1Y
4Y
GND1
GND3
GND2
GND4
2Y
3Y
2A
3A
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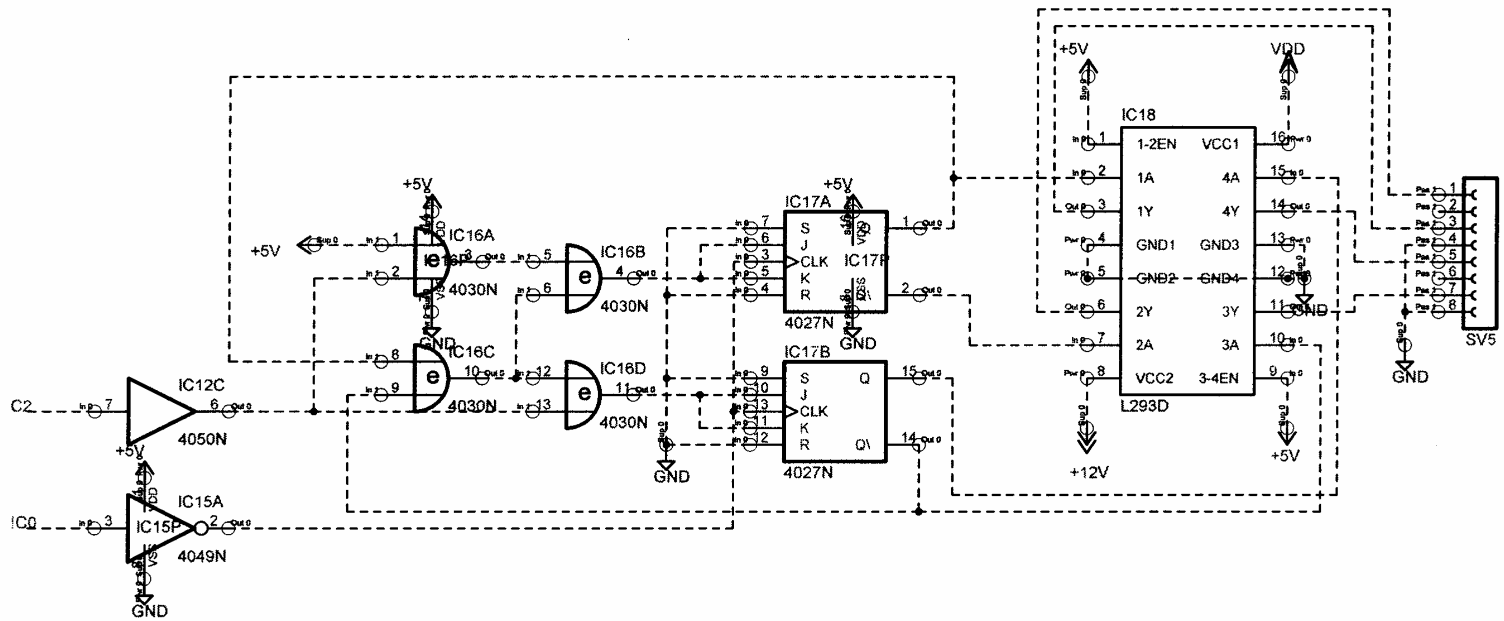


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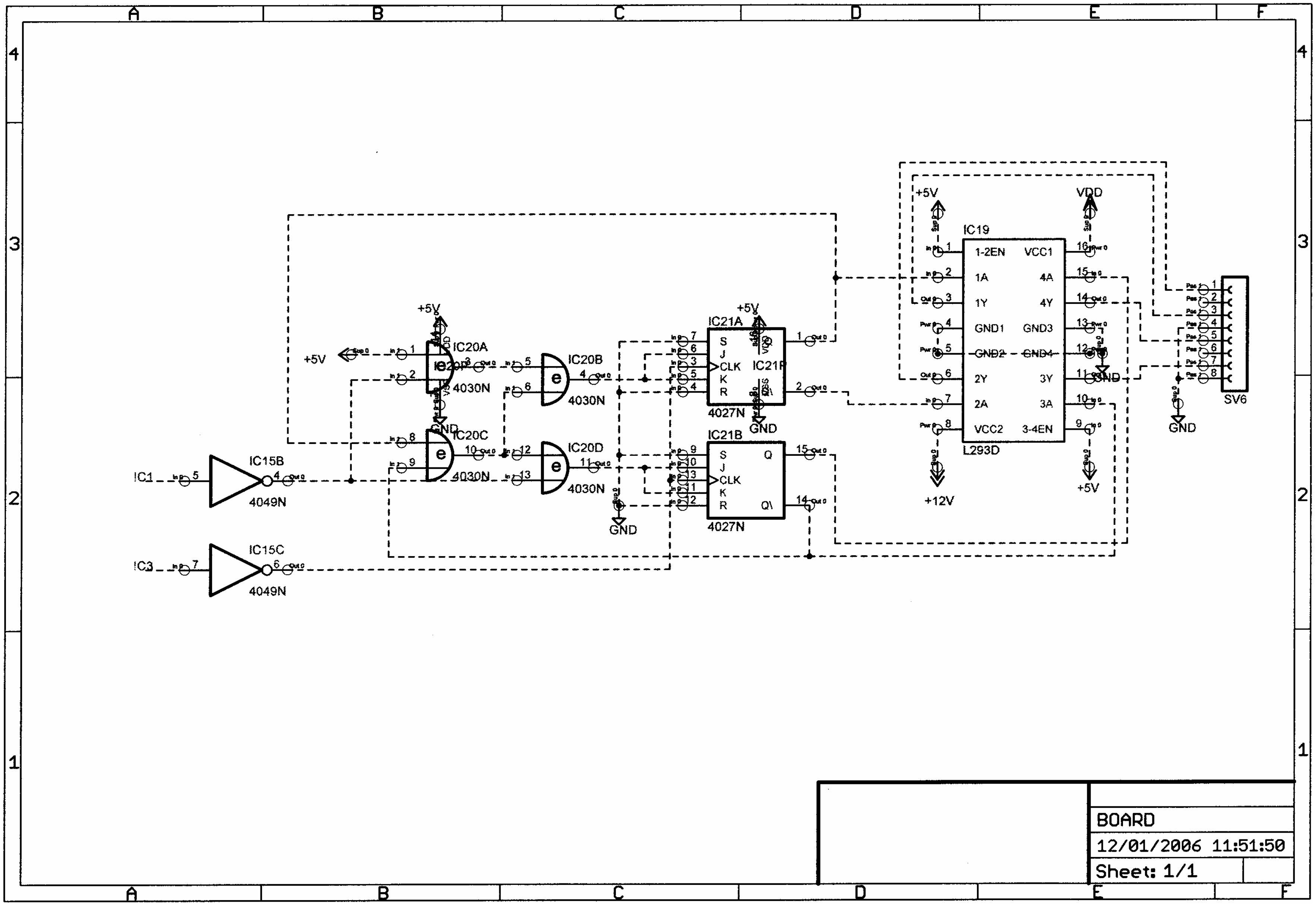
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4049N
IC15C
4049N
!C1
!C3
IC20A
IC20B
IC20C
IC20D
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IC21B
4027N
IC19
L293D
1-2EN
1A
1Y
GND1
GND2
2Y
2A
VCC2
VCC1
4A
4Y
GND3
GND4
3Y
3A
3-4EN
SV6
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+12V
VDD
GND
BOARD
12/01/2006 11:51:50
Sheet: 1/1

# B APPENDIX. ILLUSTRATED PART LIST

This appendix provides the reader with detailed drawings of the Teachmover mechanical arm. By using these drawings together with the parts list, the user should be able to identify any parts of the Teachmover and understand better how it works.

Several drawings are provided. They are:

- Figure B1. This figure shows an exploded view of the major structural components of the arm.
- Figure B2. This figure provides details of the entire, assembled manipulator and shows the details of the gears and cabling.
- Figure B3. This figure provides a different view of the cabling system and should be of great assistance when replacing worn or broken cabling.
- Figure B4. This figure provides a detailed, exploded view of the differential wrist joint.
- Figure B5. This figure provides a detailed, exploded view of the hand.

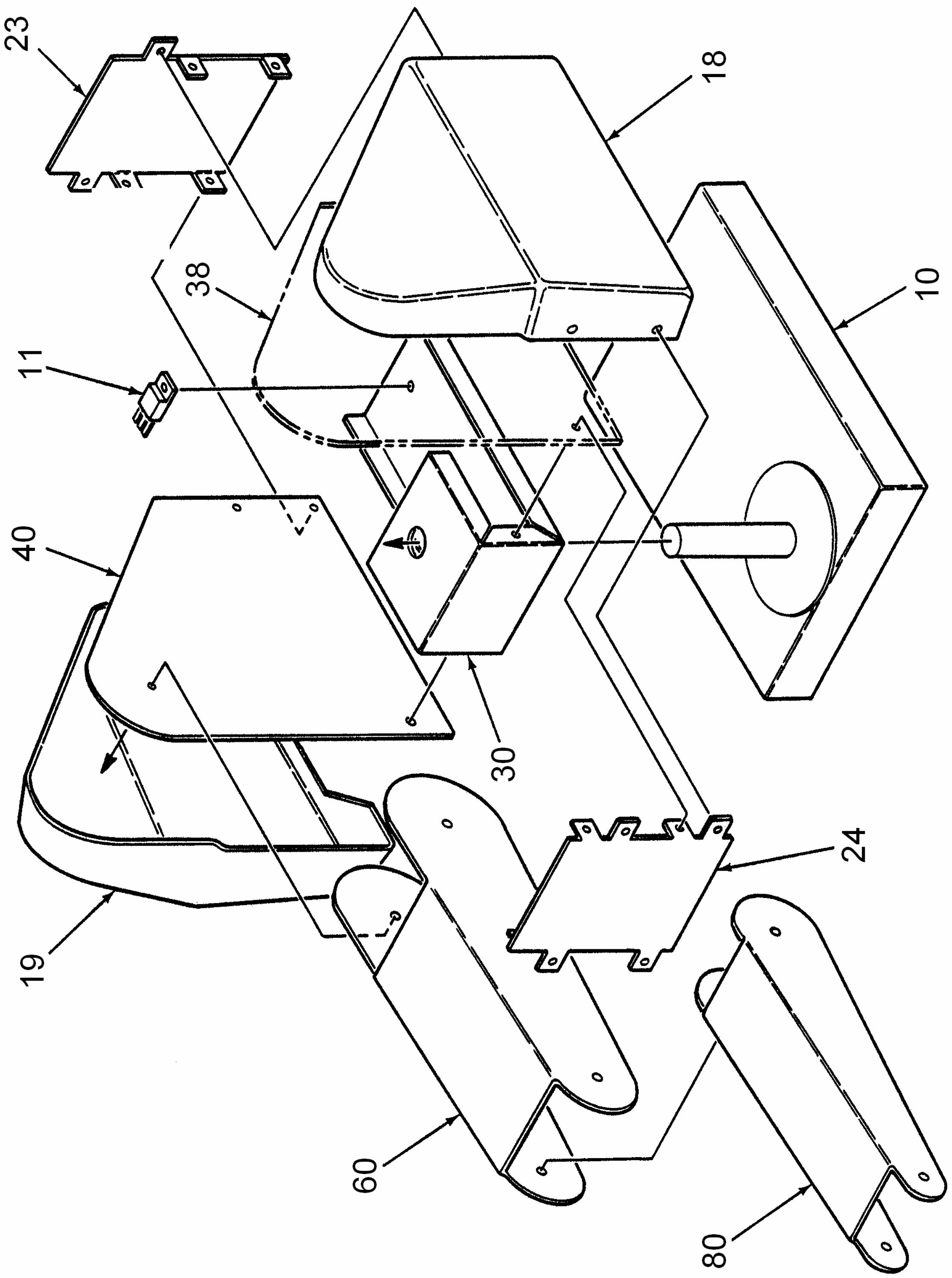


Figure B1. Exploded view of major structural components.

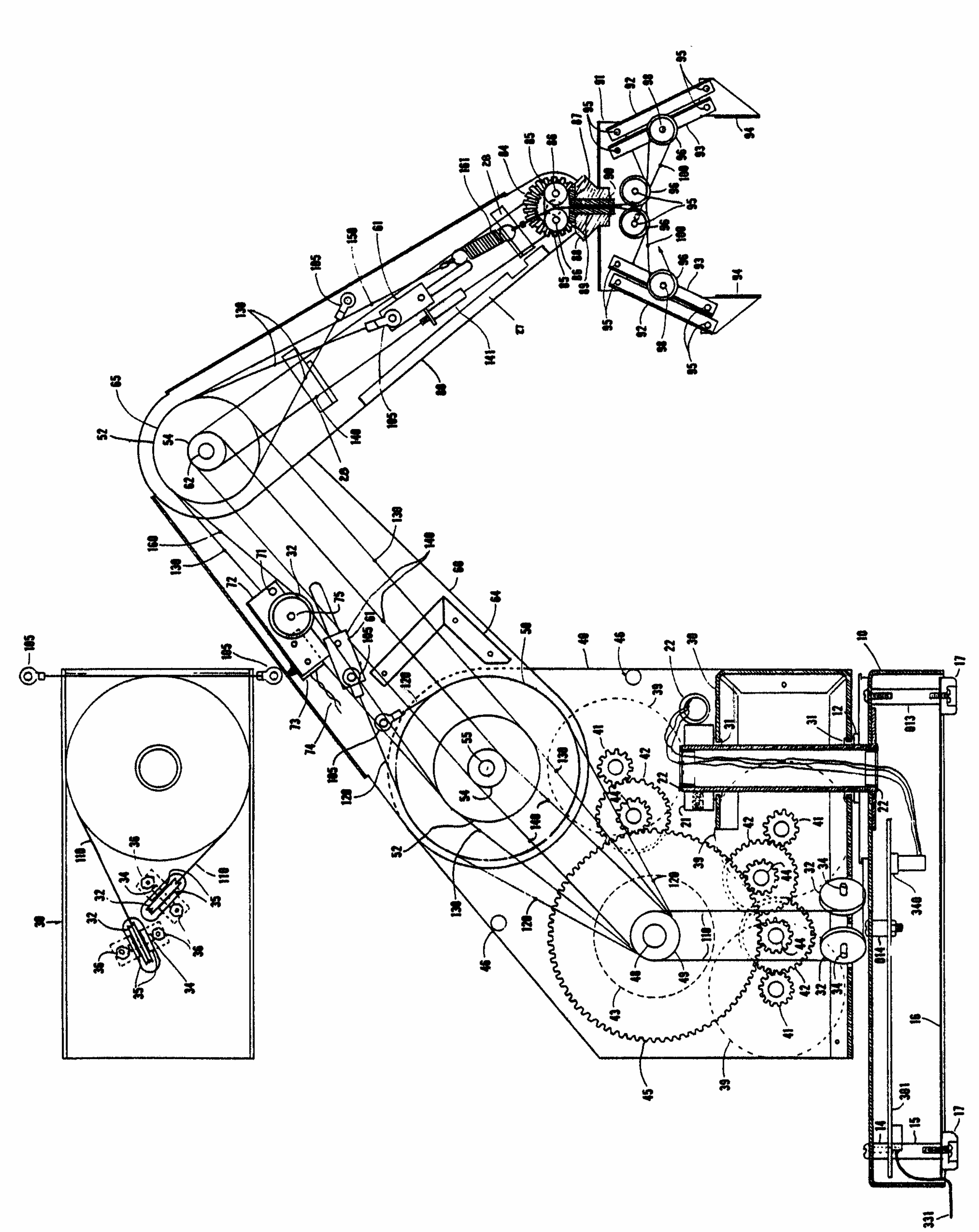

Figure B2. Detailed assembly drawing of entire arm.

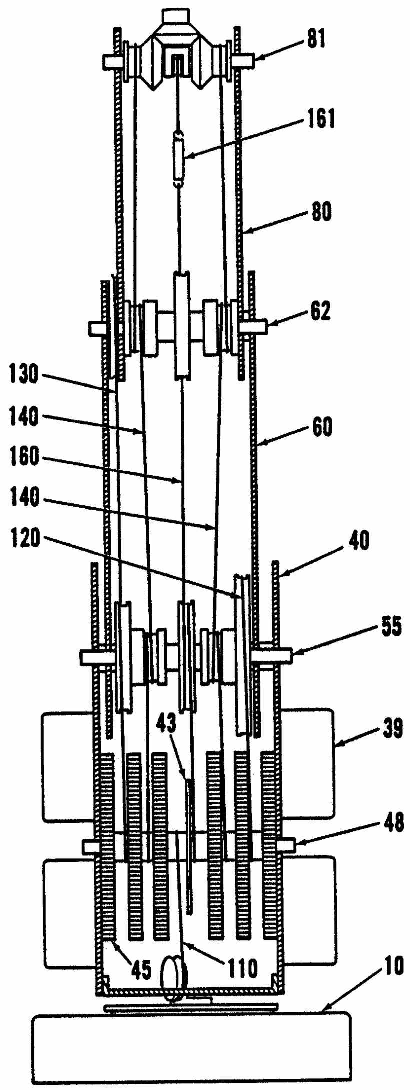


Figure B3. Detailed view of teachmover cabling.

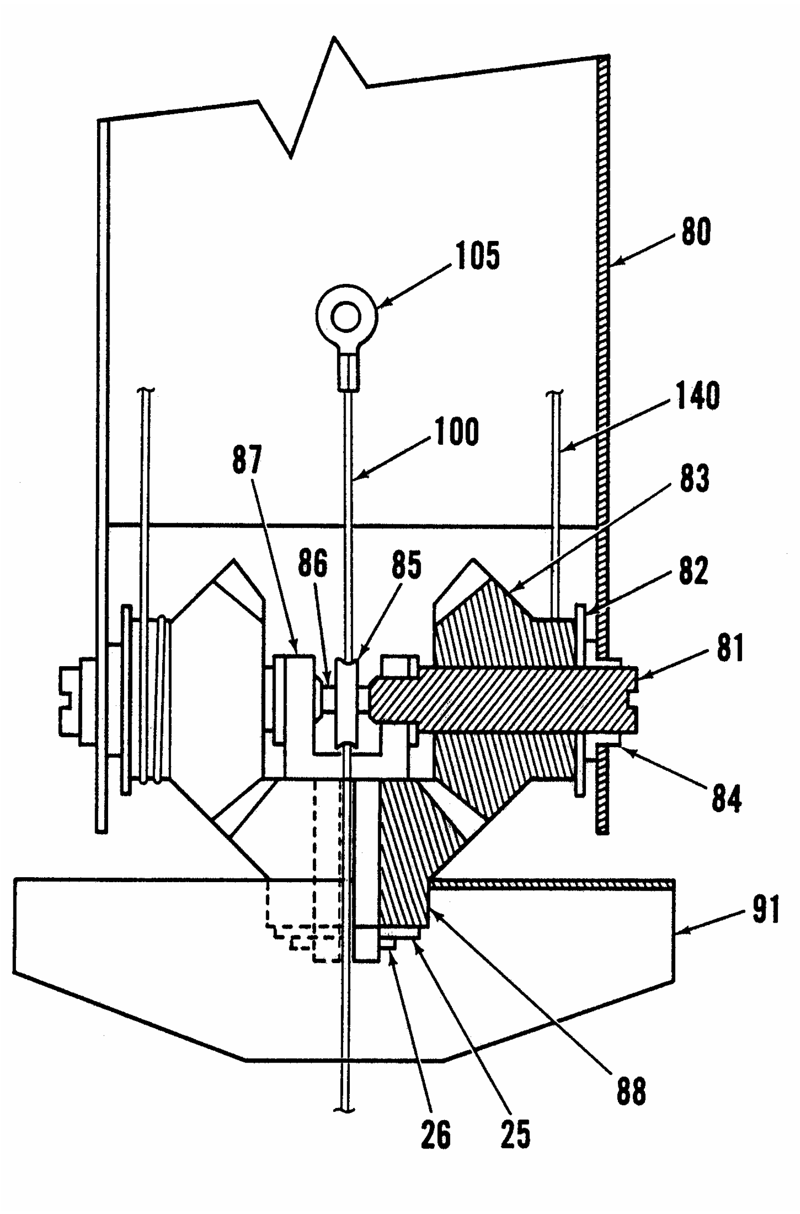


Figure B4. Detailed view of differential wrist drive.

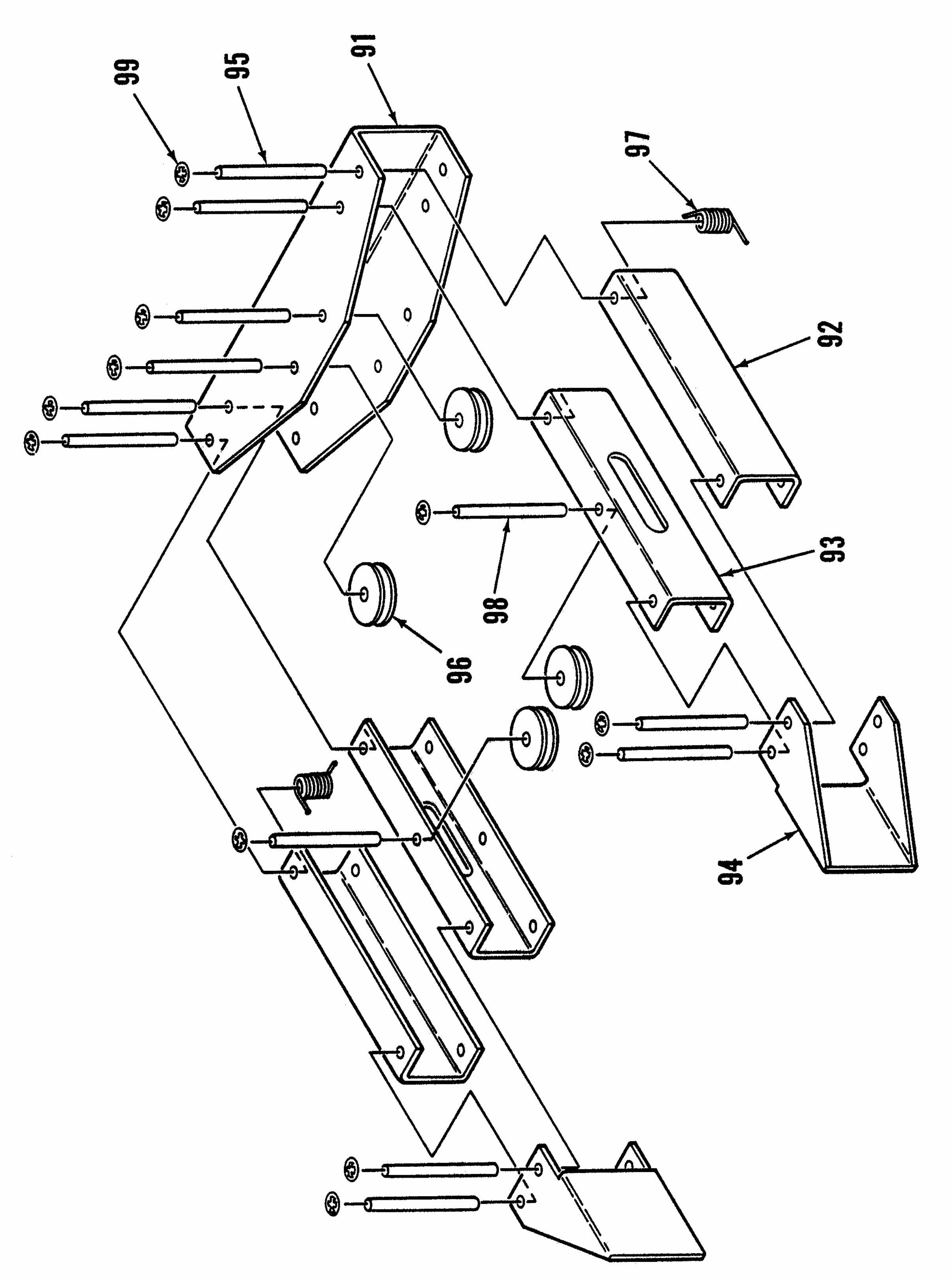


Figure B5. Exploded view of hand assembly.

**Part List**

| | |
|---|---|
| 10 | BASE |
| 11 | 5 VOLTS REGULATOR |
| 12 | THRUST WASHER |
| 13 | SPACER, LONG |
| 14 | SPACER, SHORT |
| 15 | SPACER, MEDIUM |
| 16 | BASE COVER |
| 17 | RUBBER FEET + SCREW |
| 18 | LEFT COVER |
| 19 | RIGHT COVER |
| 21 | COLLAR AND SET SCREW |
| 22 | INSULATING BUSHING |
| 23 | REAR COVER |
| 24 | FRONT COVER |
| 25 | SPRING WASHER (HAND) |
| 26 | HAND RETAINING RING |
| 27 | FOREARM STIFFNER |
| 28 | CABLE STOP |
| 30 | BODY BOX |
| 31 | BASE BEARING |
| 32 | BASE IDLER |
| 34 | BASE IDLER AXLE |
| 35 | BASE IDLER BRACKET |
| 36 | BASE IDLER SCREW |
| 38 | LEFT SIDE PLATE |
| 39 | STEPPER MOTOR WITH CONNECTOR |
| 40 | RIGHT SIDE PLATE |
| 41 | MOTOR PINION AND SET SCREW |
| 42 | COMBINATION GEAR |
| 43 | CENTER DRIVE WASHER |
| 44 | COMBINATION SHAFT |
| 45 | DRIVE GEAR AND SET SCREW |

| | |
|---|---|
| 46 | BODY SPACER |
| 48 | DRIVE SHAFT AND RETAINERS |
| 49 | DRIVE WASHER |
| 50 | SHOULDER DRIVE PULLEY |
| 52 | LARGE IDLER PULLEY |
| 54 | SMALL IDLER PULLEY |
| 55 | SHOULDER SHAFT AND RETAINERS |
| 60 | UPPER ARM |
| 61 | TENSIONING MECHANISM AND THUMB SCREWS |
| 62 | ELBOW SHAFT AND RETAINER |
| 64 | UPPER ARM STIFFENER |
| 65 | ELBOW DRIVE PULLEY |
| 71 | SENSE BRACKET SHAFT AND RETAINERS |
| 72 | SENSE BRACKET |
| 73 | MICRO-SWITCH |
| 74 | SWITCH LEADS |
| 75 | SENSE IDLER SHAFT AND RETAINERS |
| 80 | FOREARM |
| 81 | WRIST SHAFT, RETAINER AND WASHER |
| 82 | WRIST WASHER |
| 83 | WRIST MITER GEAR AND SET SCREW |
| 84 | BRONZE BEARING |
| 85 | WRIST IDLER PULLEY |
| 86 | WRIST IDLER AXLE |
| 87 | WRIST YOKE |
| 88 | HAND MITER GEAR |
| 89 | HAND SHAFT |
| 91 | HAND HOUSING |
| 92 | OUTER LINK |
| 93 | INNER LINK |
| 94 | GRIP |
| 95 | LINK PIN |
| 96 | HAND IDLER PULLEY |
| 97 | TORSION SPRING |
| 98 | INNER LINK PIN |

| | |
|---|---|
| 99 | HAND PIN RETAINER |
| 100 | HAND INTERIOR CABLE |
| 105 | CABLE TERMINATION |
| 110 | BASE CABLE |
| 120 | SHOULDER CABLE |
| 130 | ELBOW CABLE |
| 140 | WRIST CABLE |
| 160 | HAND DRIVE CABLE |
| 161 | HAND GRIP SPRING |