The ARM
Users' manual

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Warranty limits
Exact Dynamics makes no warranty for the use of this manual and assumes no responsibility for any error which may appear in this document. The information is subject to change without prior notice and should not be considered as a commitment by Exact Dynamics. Critical evaluation of this manual by the user is welcomed.

Preface

Congratulations! You've just received the ARM. It is the world's most advanced mobile wheelchair mountable robot-manipulator. It is the only one with 6 +2 degrees of freedom in movements.

For safety reasons we strongly advise you to carefully read this manual before using the ARM.

WARNING		**The ARM may not be used for manipulating sharp, hot, heavy objects and/or hazardous liquids and gasses. Neither may it be used to handle objects which may cause injuries to people, animals, or cause damage to objects or the ARM itself.**

This manual will guide you through the installation, set-up and use of the system via several interface possibilities. Please let you guide by those chapters which are describing your choice of the interface(s).

If you have any question or if you are concerned about using it or something else, please do not hesitate to contact us, see for address below.

The employees of Exact Dynamics and their retailers wish you a lot of success with your new The ARM-unit.

You may expect to work with it for many hours without any problems. Please read this manual first. You will see that many tips are given which facilitate safe and easy use. Please note that The ARM-unit may only be transported in the suitcase which has been delivered with The ARM-unit with the original foam parts.

Exact Dynamics can only be contacted regarding the originally delivered parts. For adjustments delivered by other companies, please contact these companies.

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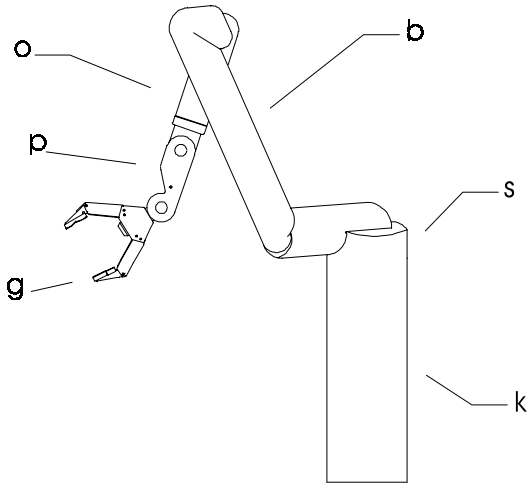
1 The ARM-unit Manipulator

1.1 The ARM-unit

In this chapter we will explain the structure of The ARM-unit and how the several parts and movements are called. Knowledge of the different terms make communication about The ARM-unit much easier. But also safer, as confusing and exchanging terms in certain cases may lead to unwanted situations.

The ARM-unit consists of the following components (some items are optional):

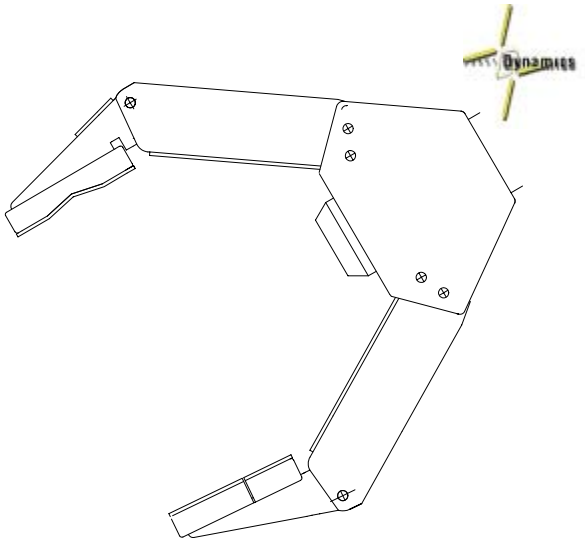
- The basic ARM
- Gripper
- Support unit (optional)
- Lift-unit (optional)
- Computerbox
- Selector box (optional)
- User input device (e.g. joystick, keypad, single switch)
- Display unit
- Suitcase
- Manual
- Software license(s)



k = Column
s = Shoulder
b = Upper arm
o = Forearm
p = Wrist
g = Gripper

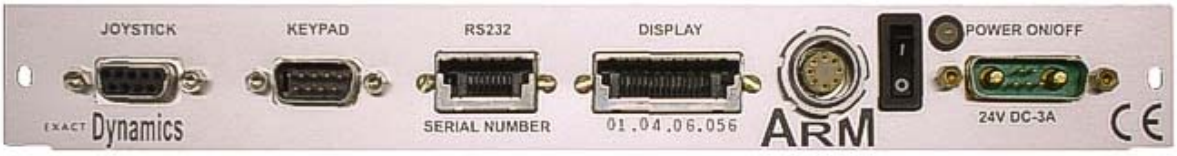
The basic ARM and gripper

Gripper
The gripper is capable to perform common tasks. It can handle bottles up to 9 cm (3.5”) width of 1.5 kg (3 Lb’s) weight. Its grasping power is 20 N (4 Lb). When grasping this power is increasing the longer the grasping command will be given until this limit has been reached. The maximum opening between the fingers is about 10 cm.



The gripper

Computer box
The computer box contains the electronic control-board which is necessary to control the ARM.



The front panel of the computer box

The following parts have to be connected to the computer box:

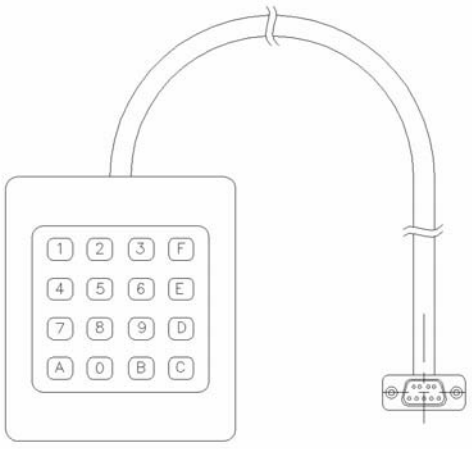
- The ARM-unit
- Keypad or joystick
- Display
- Power supply

For further details about connection see section 2.2.2.

Keypad
The Matrix 4X4 keypad is one of a soft-touch-type and is available in 4 sizes:

- small (dimension keys 17x21)
- medium (dimension keys 50x46)
- large (dimension keys 70x70)
- extra large (jumbo, dimension keys 135x175)

With this keypad the user can operate The ARM-unit (see chapter 3).

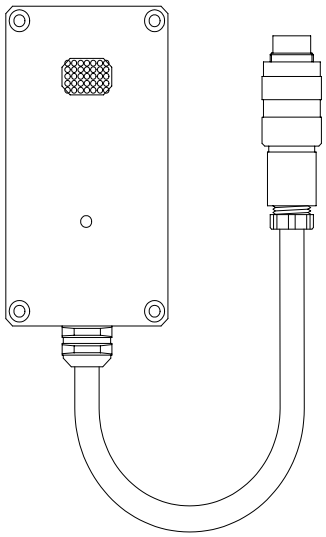


Keypad with 4×4 buttons

Display

The display unit gives information about the status of The ARM-unit. When using The ARM-unit the display screen shows in which operation mode The ARM-unit is at that moment. When you change the operation mode the signs on the display also changes immediately. In chapter 3 the signs will be explained in more detail.

When failures or errors occur, the display gives a signal. With this signal in general the failure or incorrect operation can be detected easily and quickly.



Display

Support unit

The ARM-unit basic can be mounted on a support unit. The main purpose of this unit is to connect the ARM to the lift-unit or directly to the wheelchair, bed, table, mobile base or other base. The support-unit also has an ergonomic handle with which you can take The ARM-unit easily off.

Support unit

Support unit attached to the base of ARM and the lift-unit

Lift unit

With the lift-unit The ARM-unit can be moved in vertical direction on 25 cm (10”). The lowest position is to grab things from the floor. And when it is folded in, the lift-unit is in this position. When folding out, the lift-unit automatically moves into his upper position.

Lift unit

Lift unit attached to the support unit and ARM

Selector box

It is not possible to operate the ARM using two or more input devices (such as joystick, keypad, transparent mode) simultaneously. If you want to be able the flexibly select a single input device (when you have two of more input devices available) you need a *selector box*.

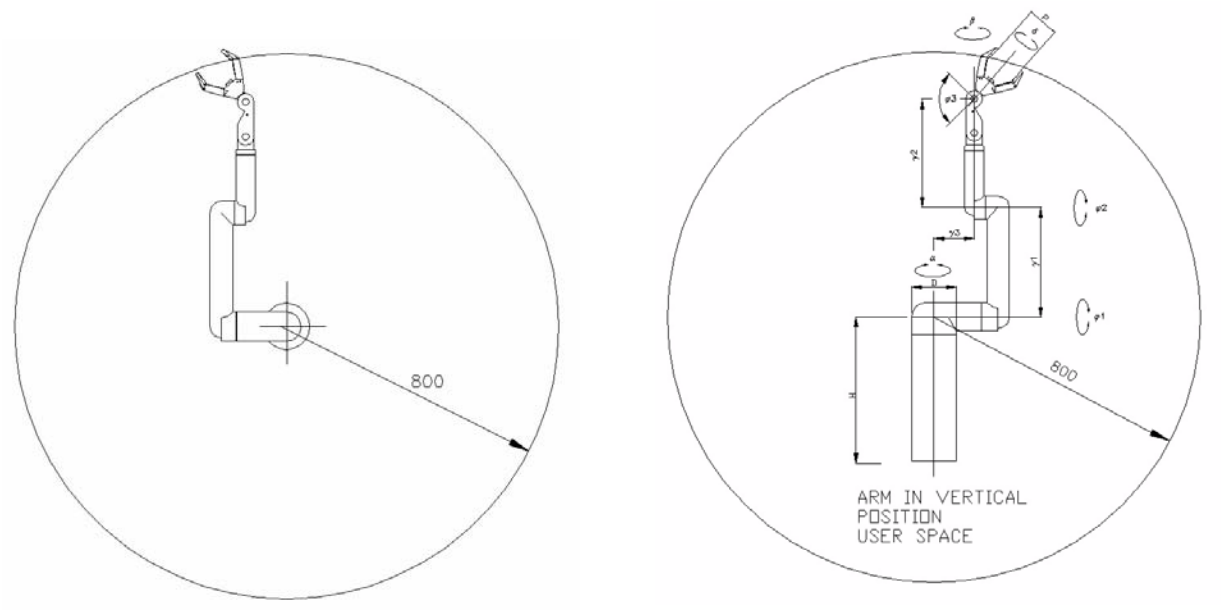
Selector box. The function of the selector switches (S1, S2 and S3) shown in this figure may vary differ on your selector box.

An input device must be selected prior to switching on the ARM, by setting the appropriate buttons on the software selector box. Also a button for remotely switching the ARM on and off is available. This switch will only work when the POWER ON/OFF switch on the form panel of the computer box is on.

1.2 Use of The ARM-unit

1.2.1 The properties of The ARM-unit manipulator

In this chapter we will amplify on the properties of The ARM-unit. This is also called the functionality of The ARM-unit.



As shown in the figures above the range of The ARM-unit can be indicated in a spherecal shape with a radius of 80 cm. Due to the use of the lift-unit there are two spherical working spaces of The ARM-unit.

The ARM-unit has a maximum lifting capacity of appr. 1,5 kg (3 Lb's). When trying to lift objects heavier than 1,5 kg. there is a possibility that the display shows a warning.

The ARM-unit has built in slip-couplings to prevent The ARM-unit from damage. They are designed for safety purpose not for regular use.

The maximum speed of The ARM-unit is the speed with which The ARM-unit can move an object (held in the gripper) in space. This speed is adjusted at 25 cm/sec.

1.2.2 Tips for save use of The ARM-unit

Further to a survey held in 1996 under several users of The ARM-unit a list has been made up. This list shows the several activities of the users with The ARM-unit.
A few of these activities are:

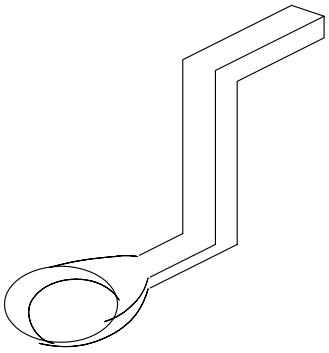
1. All day activities being as independent as possible e.g.:
- pouring a drink
- making dinner
- eating and drinking
- getting a drink on a terrace and toasting
- taking medicines
- washing and drying
- scratching face
- putting on and off your glasses and positioning precisely
- shaving electrically
- opening doors and windows
- using switches
- watering plants
- opening a tap
- shopping
- positioning keypad, your forearm, etc.
- opening drawers
- grabbing things (from the floor)
- playing with pets especially dogs
- playing games

2. Working activities being as independent as possible e.g.:
- all day activities during working hours, see 1
- operating the computer
- operating the printer
- making telephone calls
- removing diskettes
- exchanging tapes
- switching pages

To prevent that these activities are not dangerous for the user, we hereby must ask your attention for the warnings and for using your common sense.

Safe eating and drinking

Eating with cutlery may cause a dangerous situation. Please read the following tips carefully.



- To prevent that the spoon hits the plate, it is a good suggestion to bend the spoon (see drawing). The distance between gripper and plate is larger now.
- It is often a problem to dish up, as food is spoiled or the plate will move. Special plates with rims and antiskid mats are available.
- As eating with The ARM-unit does not go very fast, the food will be cold. To prevent this special warmed up plates are available.
- Ladle out soup is often a problem, the best solution is to use a special cup with spout.

Please note: never manipulate the cutlery in your mouth!

Hot food and hot beverages may injure you, when spilled over you. Therefore, consuming hot food and hot beverages using the ARM are forbidden, unless you are using a special designed dinner plates, soup plates, cups, mugs and glasses which prevent spilling. To drink, the gripper of the ARM-unit (with cup) has to approach you from a side. Then when the cup/mug/glass is just in front of your mouth, use the *drinking mode* of the ARM to drink. Note that it is safer to use a straw.

WARNING		**The ARM may not be used for manipulating sharp, hot, heavy objects and/or hazardous liquids and gasses. Neither may it be used to handle objects which may cause injuries to people, animals, or cause damage to objects or the ARM itself.**

1.3 Safety

For safety reasons many precautions were taken such as:

- The motor power has been maximised by maximising the current.
- There is an operating system with a feedback for controlling speed, gears and position. The display shows a sign if something is wrong.
- In the Cartesian mode the display beeps when the gripper arrives a forbidden area.
- To move The ARM-unit the joystick or the concerning button of the keypad has to be pushed continuously. The ARM-unit will stop immediately when leaving the button or the joystick .
- There is a mechanical safety by means of the slip-couplings.
- The ergonomic design is responsible for the friendly shapes and forms.

Safe use of The ARM-unit requires a few things of the user. The user is also responsible for safe use of The ARM-unit. Exact Dynamics is not responsible for any damage or harm caused by unsafe use of The ARM-unit.

When using The ARM-unit the following prescriptions have to be considered:

- The ARM-unit may not be used to put something in or on the body. An operation failure could lead to dangerous situations. The following list shows a few examples:
    - it is not allowed to smoke or to work with fire;
    - it is not allowed to give an injection;
    - do not move food in the mouth, but position the food just in front of the mouth and eat by moving your head.
- The ARM-unit cannot be used for lifting and moving objects heavier than 1,5 kg.
- The ARM-unit may not be used to lift or move objects with hot substance.
- Do not push more than one button at the time.
- Do not handle sharp objects with The ARM-unit.
- It is not allowed to operate the wheelchair with The ARM-unit.

WARNING		**The ARM may not be used for manipulating sharp, hot, heavy objects and/or hazardous liquids and gasses. Neither may it be used to handle objects which may cause injuries to people, animals, or cause damage to objects or the ARM itself.**

1.3.1 Limitations of The ARM-unit

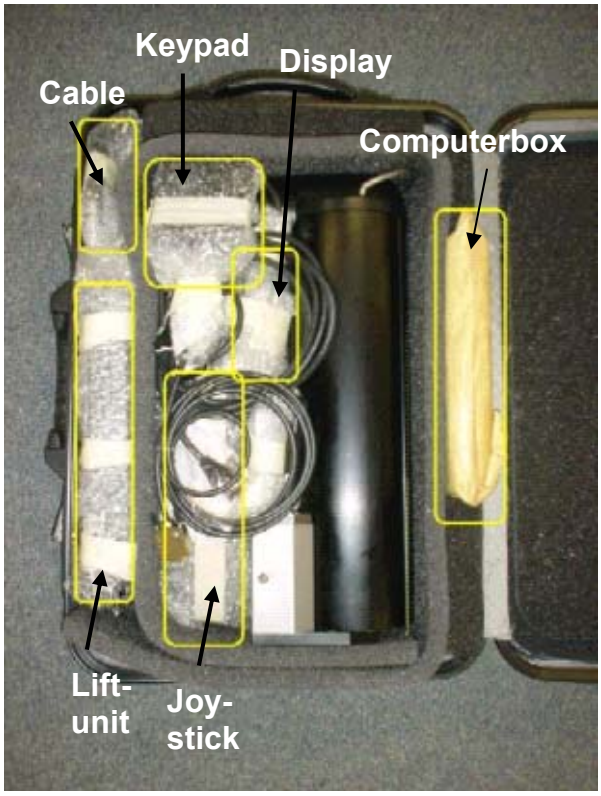
To prevent that the ARM gets damaged, the following limitations must be considered:

- The ARM is meant for indoor use.
- Any collision of the ARM with objects must be avoided. (Therefore the ARM may not be used for example for like games like wheelchair hockey).
- The ARM-unit may not be dropped.
- The ARM-unit may not be exposed to aggressive environments, like sand, and aggressive substances.
- The wrist may not be immersed into water.
- The ARM may partly fold out if the wheelchair takes a turn at high speed.
- If the battery power is too low the ARM will shut itself off.
- We advise you to use the lift-unit in its highest or lowest position only, especially when you are driving the wheelchair.
- The ARM-unit may only by used by those who can operate The ARM-unit safely.
- It is not allowed to use The ARM-unit for lifting and using hot, sharp and dangerous materials and objects.
- External factors which can cause a temperature of The ARM-unit of >50° or <-5° have to be avoided. It is not allowed to use The ARM-unit under these conditions. Transport or storage under the condition >60° or <-20° can cause damage to the electronics and electro-mechanics.
- It is not allowed to use, transport or store The ARM-unit in places where the humidity is more than 90% (or in rain or in other humid environments). This can cause damage to electronics and electro-mechanics.
- Other external factors which can bring power to bear on The ARM-unit (like vibrations, G-forces, etc.) have to be avoided.
- It is not allowed to let somebody else, than the user, operate the ARM while the user is in the wheelchair or near the ARM.

2 Transport & Installation

2.1 Transport instructions

The ARM-unit may only be transported in the original suitcase it came in, and packed with the original foam parts. The figures below show the location of the parts and units of the ARM unit in the suitcase.



Location of parts in the suitecase

Location of the ARM-unit in the suitcase

Transport (or storage) at temperatures higher than 60°C or lower than -20°C can cause damage to the electronics and electro-mechanics, and is therefore not allowed.

2.2 Installation instructions

2.2.1 Attaching and detaching The ARM-unit to the wheelchair

The ARM-unit manipulator is a mobile manipulator which is suited for coupling to a wheel-chair. Also in non-mobile situations (i.e. in a fixed environment) The ARM-unit can be used very well. For attaching The ARM-unit to its environment a universal coupling system has been developed. The ARM-unit can be easily attached and detached to the lift unit.

Attaching the ARM to the support unit

WARNING

The ARM may only be attached to the wheelchair when:

- The ARM is folded,
- The ARM-unit is switched off, and
- if the lift-unit is in the highest or lowest position (the lowest position is preferred!)

Take the following steps to ***attach*** The ARM-unit:

1. Make sure that the handle of the support unit in the position marked by the red dot •

2. Hold the ARM at the handle near the shoulder and tilt it slightly towards the lift unit

3. Lower the ARM vertically onto the upper pin of the lift unit and rotate it gently to meet the lower pin

4. Push the handle of the support unit away from the base of the ARM, marked by the green dot •

Detaching the ARM from the support unit

WARNING

The ARM may only be attached to the wheelchair when:

- The ARM is folded,
- The ARM-unit is switched off, and
- if the lift-unit is in the highest or lowest position (the lowest position is preferred!)

Take the following steps to ***detach*** The ARM-unit:

1. Push the handle of the support unit towards base of the ARM, marked by the red dot •

2. Hold the ARM at the handle near the shoulder and tilt the ARM towards the lift unit.

3. Take the ARM from the upper pin of the lift-unit by lifting it vertically.

After detaching The ARM-unit has to be stored carefully at a safe place. In case that The ARM-unit has to be stored for a long time, or if it has to be sent, then it is strongly

recommended to put the ARM back in the suitcase which has been delivered together with The ARM-unit (see previous section).

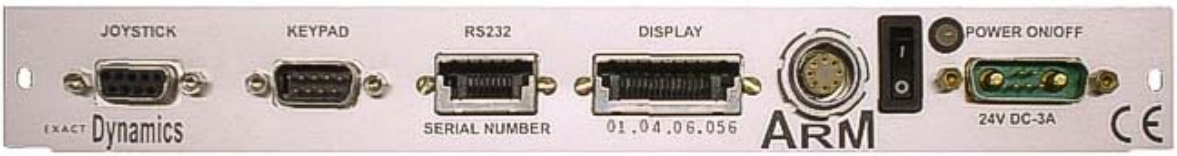
Note: It is not necessary to have a lift-unit. In such a case the coupling system can for example be directly attached to the wheel-chair.

2.2.2 Connections of different parts to the processor box

The ARM-unit arm should be connected to the computer box via a cable which is connected to the Lift-unit at the other side.

WARNING Switch off the computer box before connecting or disconnecting any cable to, or from, the computer box.

The figure below shows the front panel of the processor box.



Front panel of the computer box

From left to right, the plugs and switch on the front panel are:

- JOYSTICK
  If you use an *analog* joystick you should connect its cable to the JOYSTICK connector. If you use a digital joystick you should connect it to the KEYPAD connector on the front panel. Note: It is not possible to use two or more input devices to operate the ARM.

- KEYPAD
  If you use a 4x4 keypad you should connect its cable to the KEYPAD connector. If you use a *digital* joystick you should connect its cable to the KEYPAD connector. Note: It is not possible to use two or more input devices to operate the ARM.

- RS232
  The RS232 connector is not used.

- DISPLAY
  Connect the cable of the display to the DISPLAY connector.

- ARM
  Connect the cable from the lift unit to the ARM connector on the front planel. In the case you do not have a lift unit, connect the *special male connector part* to this connector.

- POWER ON/OFF switch
  Use the POWER ON/OFF switch to switch on or off the ARM unit. The light next to the switch indicates whether the ARM unit is on or off. If the light is *green*, the ARM is on. If the light is red the voltage of the power supply (batteries) is too low. Warning: Switch off the computer box before connecting or disconnecting any cable to, or from, the computer box.

WARNING		Switch off the ARM unit if the light next to the *on/off switch* is red. And charge the batteries before switching on the ARM.

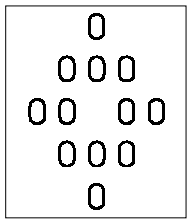
- 24V DC-3A
  The ARM-unit requires a 24 V DC-3A power supply. Connect the mains supply from the power supply, usually batteries, to the 24V DC-3A connector. The ARM-unit comes with a plug to be connected to the 24V DC-3A connector. The connection scheme (pin-layout) of this connector is supplied on a separate sheet coming with the ARM.

2.2.3 Electronic test

Take the following steps to perform an electronic test of the ARM:

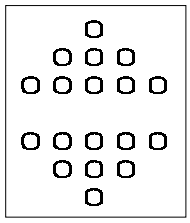
1. Switch off the computer box
2. Connect the main power supply to the computer box
3. Connect an input device to the computer box
4. Make sure the ARM is folded in
5. Make sure the lift unit is in its lowest position
6. Switch on the ARM

During startup the display-unit shows the following symbol:



Next, The ARM-unit will execute a start-up test. The gripper will close. The display unit gives a beep after the starting test has been finished.

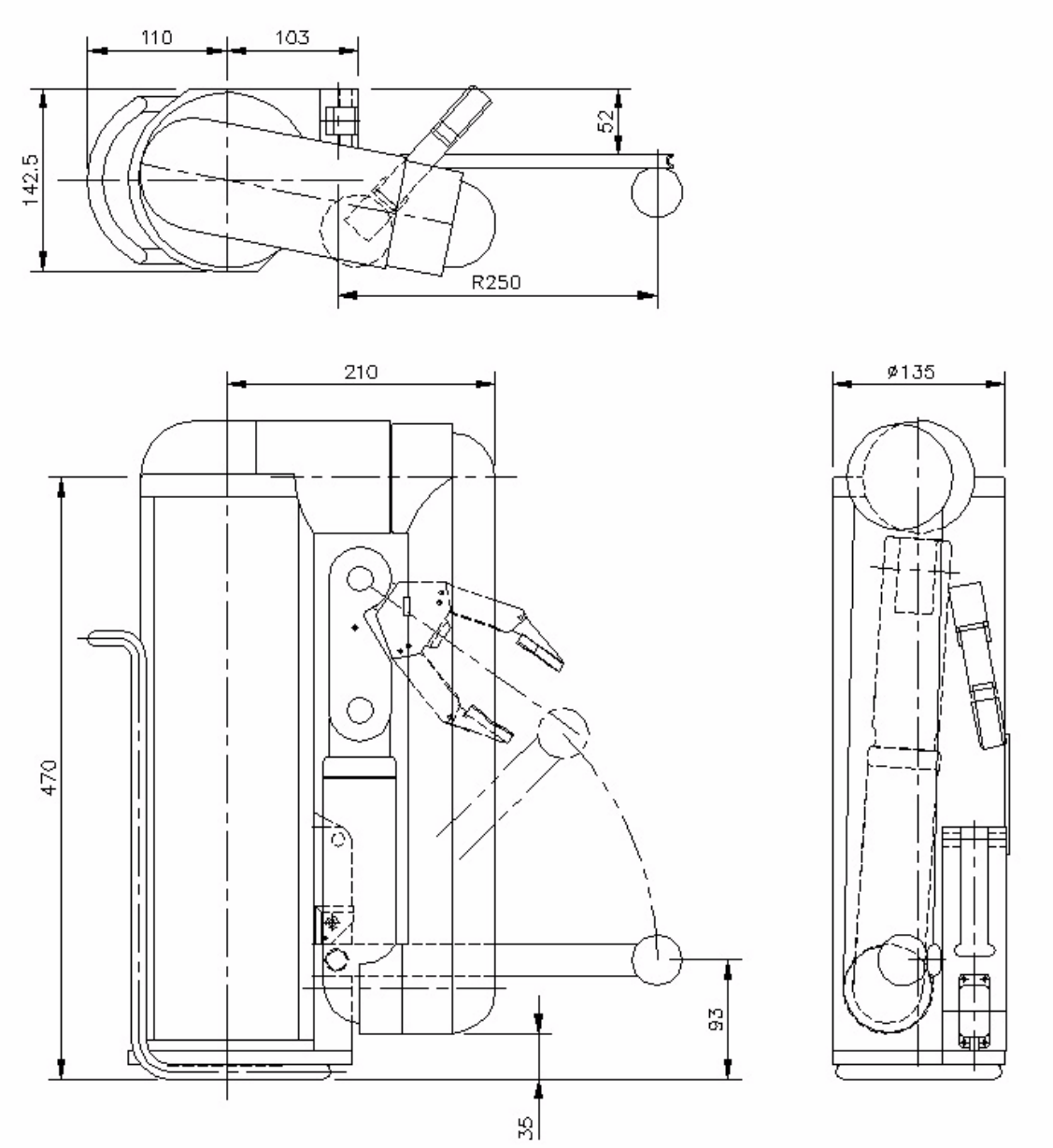
In the case you use a keypad, the folding out symbol is shown on the display unit:



Next The ARM-unit can be used following the instructions as described in chapter 3.

2.2.4 Dimensions of The ARM-unit

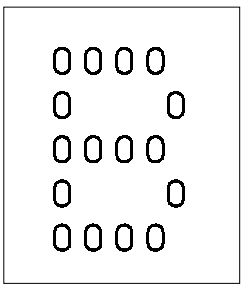
In the picture below the mechanical dimensions of The ARM-unit can be found:



3 Operation of The ARM-unit

3.1 *Tips for efficient use*

- Use the Lift-unit preferably only in the utmost High or utmost Low position.
- When The ARM-unit is not used for a considerably time, then fold it in and switch The ARM-unit off.
- In case a high force should be delivered (for example for opening a refrigerator), then a blocked motor signal can occur. This means that the motor can not deliver the required force.



This signal warns the user that the force which is asked for is too high.

WARNING  In joint mode no, so called *prohibited area's* are defined. This for examples implies that you can steer the gripper such that it collides with the base of the ARM. Therefore, be careful when using joint mode.

3.2 *Use of the 4X4 MATRIX KEYPAD*

The 4X4 matrix keypad consists of 16 keys which are positioned as follows:

1,1	1,2	1,3	1,4
2,1	2,2	2,3	2,4
3,1	3,2	3,3	3,4
4,1	4,2	4,3	4,4

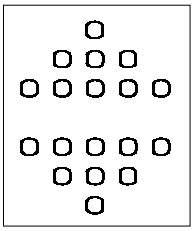
3.3 Starting with The ARM-unit

Starting point of this chapter is that The ARM-unit is correctly installed according to the installation description of the previous chapter. The following parts should be connected to the processor box:

- Power supply (batteries)
- The ARM-unit arm
- An input device
- Display-unit

The ARM-unit can be started according to the following procedure:

- Switch on the ARM
- Wait until the start-up procedure is finished. The gripper opened and closed itself.
- Then the display now shows the following symbol:



- Press key 1,1 until The ARM-unit fully has been folded out (that is, the ARM does not move anymore). This pre-programmed movement can only be executed if The ARM-unit was folded in correctly.

The ARM-unit can now be used.

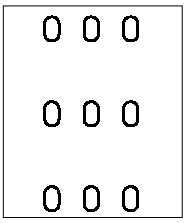
The ARM-unit can be folded in as follows:

-Go to the mode selection mode (key 3,3);
-Select the *fold in* mode (key 1,2);
-Press key 1,2 until the arm is fully folded in. (Wait until the beep.)

After folding out The ARM-unit is still in the *folding* out mode. The figure below gives the meaning of the keys in this mode:

The ARM-unit folds out	**1,2**	**1,3**	**1,4**
2,1	**2,2**	**2,3**	**2,4**
3,1	**3,2**	**3,3**	**3,4**
Main mode	**4,2**	**4,3**	**4,4**

If key 4.1 is pressed after folding out, then the main mode will be selected.

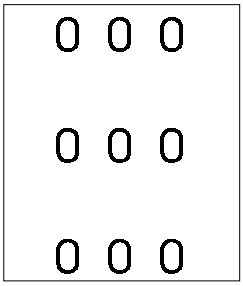


3.4 Use of The ARM-unit MANIPULATOR

3.4.1 Keypad configuration menu

From all submenus the main menu can be selected via key 4,1.

When the main menu is reached, the following symbol will appear on the display:



display symbol main menu

Via the main menu all sub-menu's can be reached. The submenus for each key are shown in the figure below:

Folding out	**Drinking**		**Joint menu**
Folding in	**Drinking back**		
Velocity	**Up**		**Lifting Up**
Main	**Down**		**Lifting Down**

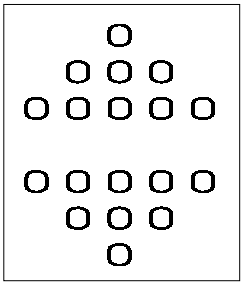
Figure keypad "Main menu"

3.4.2 Menu for folding out

The folding out and folding in movements are so called pre-programmed motions.

The folding out menu can be reached from the main menu by continuously pressing key 1,1. Leaving the key The ARM-unit stops and will continue after pressing again.

After the folding out menu has been reached the following symbol will appear on the display:



In the folding out menu The ARM-unit can be folded out by pressing key 1,1.

Folding out			
Main			

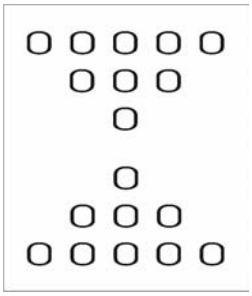
Figure keypad fold out menu

The ARM-unit will fold out if key 1,1 is continuously pressed.

3.4.3 Menu for folding in

Via the main menu it is possible to reach the folding in menu.

As soon as being in the folding in menu, the following symbol will appear on the display:



In the folding in menu, The ARM-unit can be folded in by pressing key 1,2 continuously.

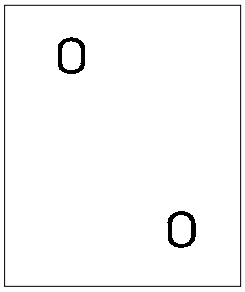
Folding in			
Main			

Figure keypad *fold in* menu

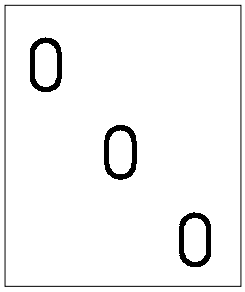
Remark: Fold The ARM-unit in until the beep.
Only then The ARM-unit is fully folded in. Only in this case the fold out routine can be executed.

3.4.4 Velocity menu

The velocity menu can be reached by pressing key 3,1 in the main menu.
The velocity can be adapted by pressing key 3,1 again. The velocity will switch between slow and quick. The current velocity can be seen on the display unit:



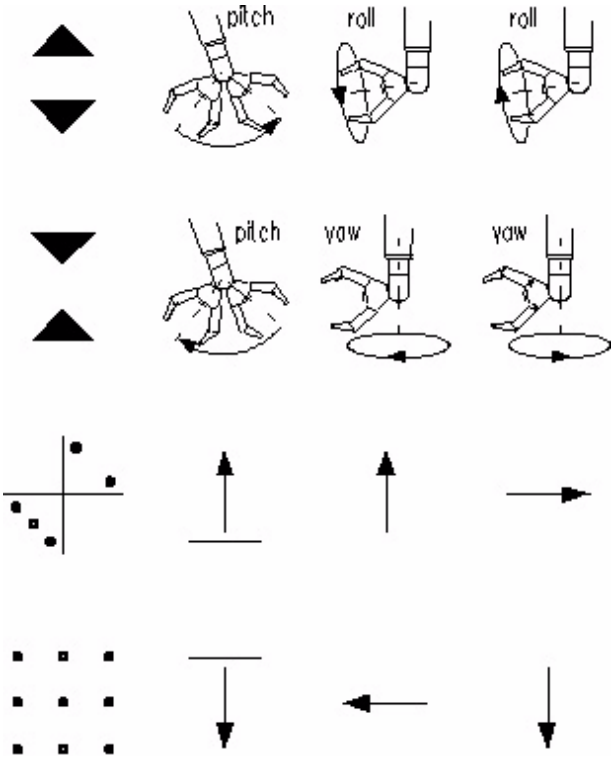
Slow



quick

In the figure below it is shown which movements can be made in the velocity menu menu:

Figure keypad "velocity menu"



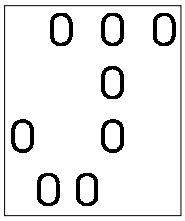
3.4.5 Joint menu

Via the main menu the joint menu can be reached via key 1.4.

In the joint menu all axes can be steered independently.

WARNING In joint mode no, so called *prohibited area's* are defined. This for examples implies that you can steer the gripper such that it collides with the base of the ARM. Therefore, be careful when using joint mode.

After the joint menu has been reached the following symbol will appear on the display:



Below the keyboard for the joint menu can be found:

open gripper	**wrist jaw**	**rotate gripper**	**rotate gripper**
close gripper	**wrist jaw**	**rotate wrist**	**rotate wrist**
	rotate under arm	**rotate upper arm**	**rotate shoulder**
Main	**rotate under arm**	**rotate shoulder**	**rotate upper arm**

Figure keypad " jointmenu left "

3.5 Use of the Lift-unit

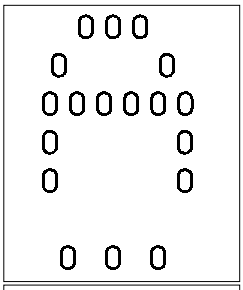
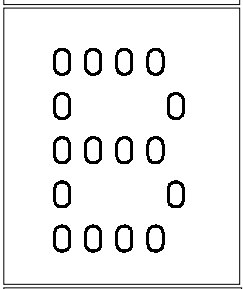
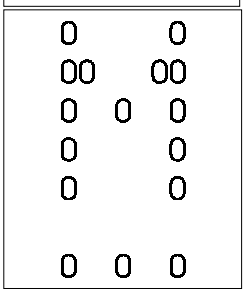
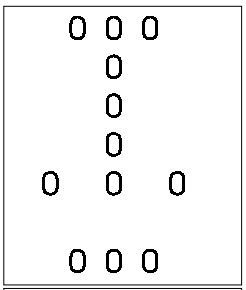
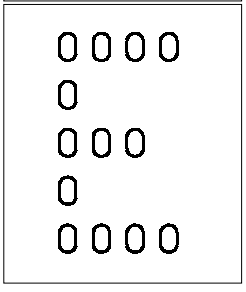
The lift-unit can be used within the main menu. The lift- unit has two operating positions:

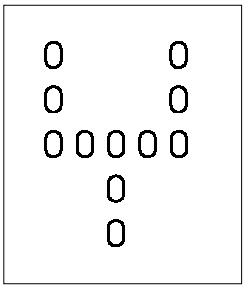
- Utmost position high
- Utmost position low

It is preferable to use only these positions, because the high low unit is sufficient stable in these positions only.
The high low unit can be steered **up** via key 3,4, and steer **down** via key 4,4.

3.6 Troubleshooting

Due to wrong usage of system errors The ARM-unit may refuse to work anymore. In this case a warning symbol is shown at the display unit. The list below describes which errors may occur, which display symbols belong to them, and which actions can be taken:

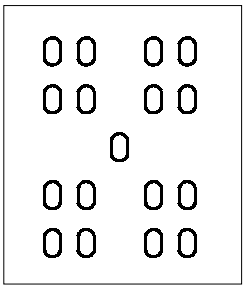
DISPLAY SYMBOL	ERROR	ACTION
	Error in the **A**bsolute Measuring system.	Switch the on/off switch off.
	Initialisation error.	Take a second trial to restart The ARM-unit. If a few trials do not work, then contact your supplier.
	**B**locked motor.	Move in the other direction. Look if one axes is blocked, or if too heavy load is transported.
	Move without input	Restart The ARM-unit by switching it of and on again. If this does not solve the problem contact your supplier.
BLINKING!		
	Internal communication warning	Contact your supplier.
	Electrical error	Restart The ARM-unit by switching it of and on again. If this does not solve the problem contact your supplier.



BLINKING

Gripper moves against wrist.

Move gripper back in the opposite direction.



BLINKING

Wrong position for **X**YZ modes.

Folding in/out is impossible from this position.

Move back to the normal position for XYZ modes with the joint menu.
Move with help of the joint menu to a position from which The ARM-unit car folded in/out.

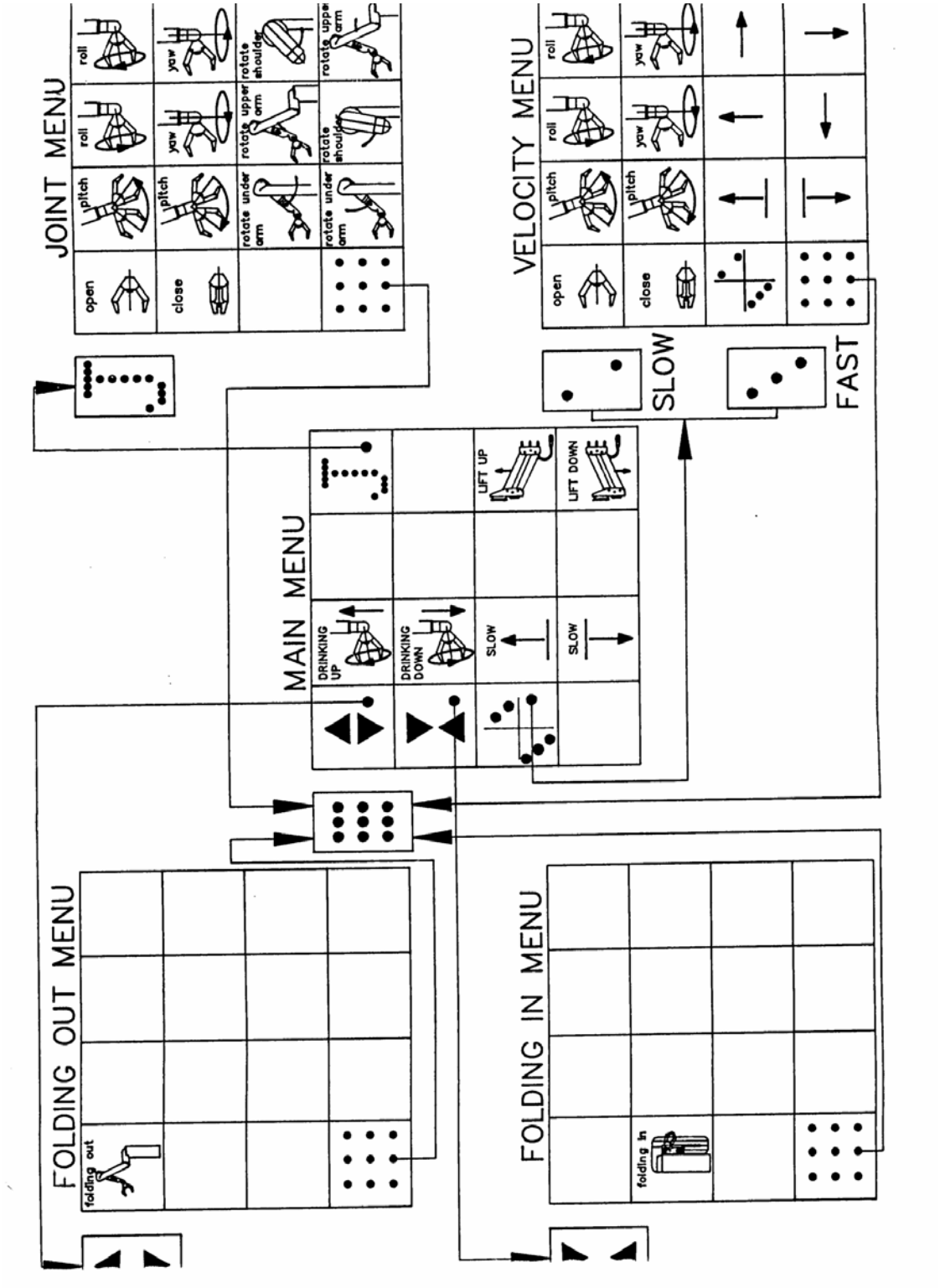
If any other problems exist, or if the actions described above do not work,

PLEASE CONTACT YOUR SUPPLIER!

4 Operating the ARM using keypad or joystick

4.1 Keypad control

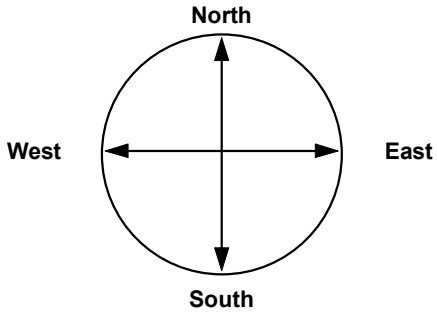
The figure below shows an overview of the menu structure when using the keypad.



4.2 Joystick control

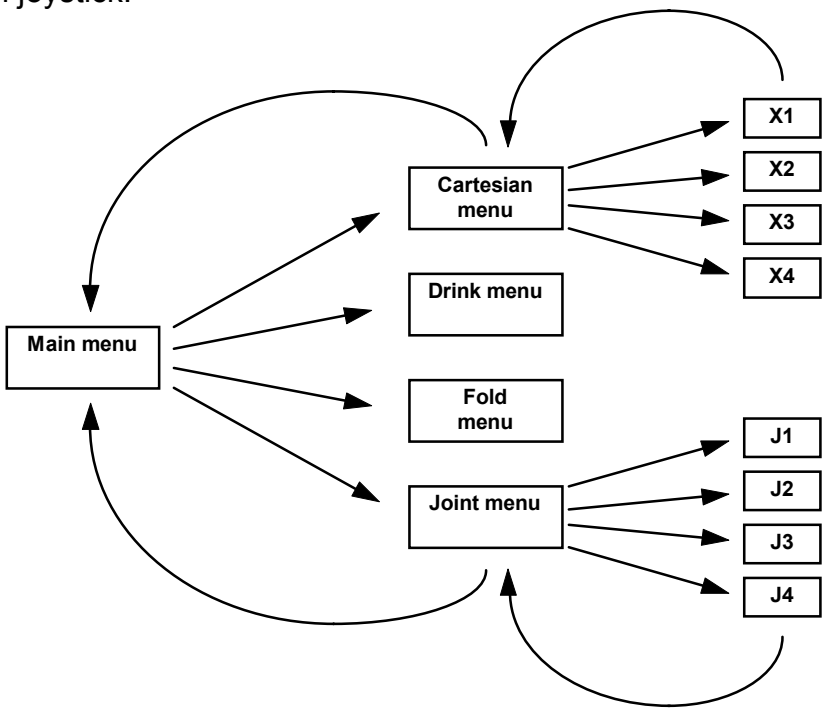
Description menu-structure

The short joystick control uses 4 wind-directions for controlling The ARM-unit:



Naming the four directions of the joystick (wind-directions)

The figure below shows the menu-structure when controlling the ARM using a 4-wind-direction joystick.

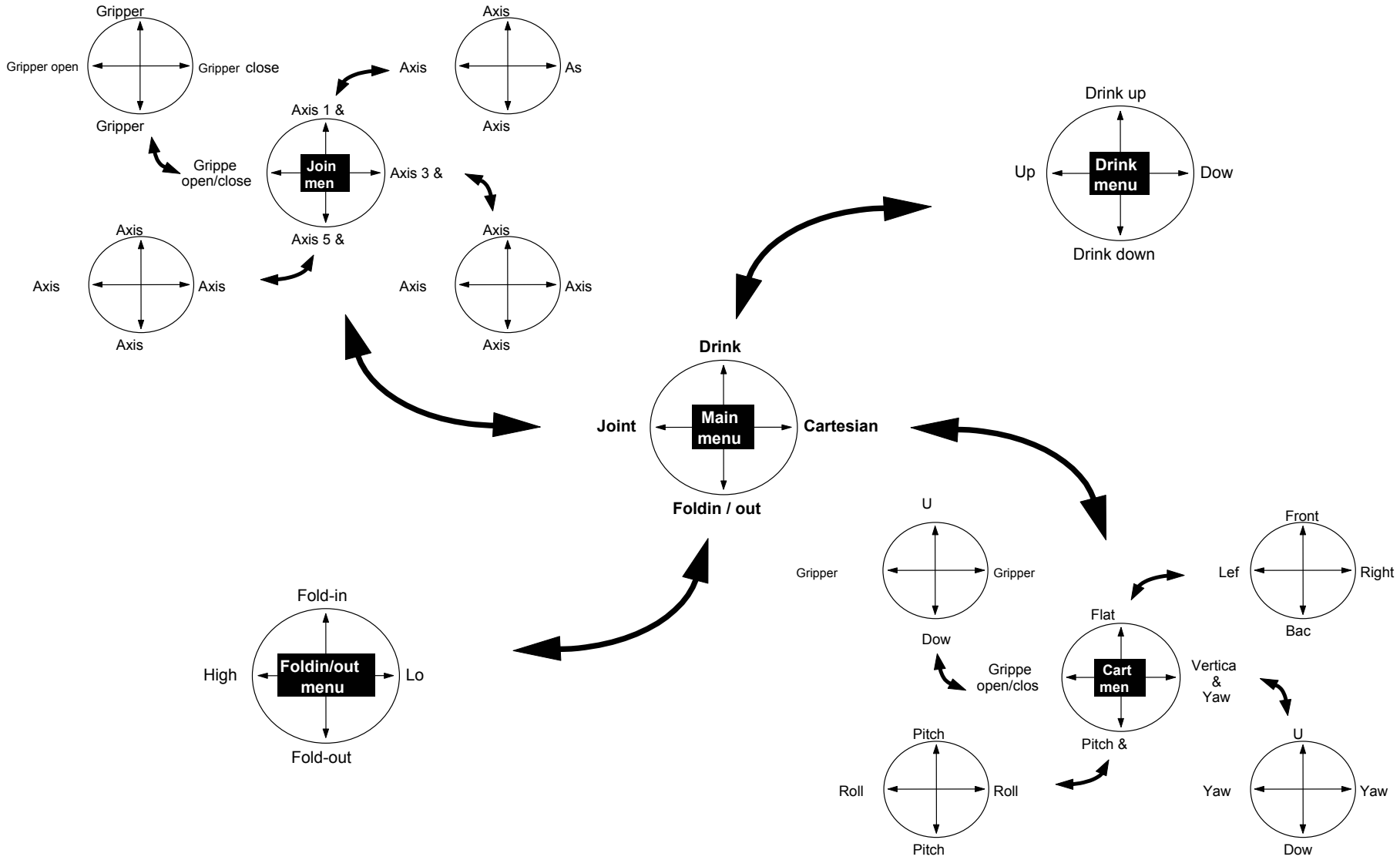


Menu-structure joystick control

This structure consists of a main-menu with submenus for cartesian, joint, fold and drink movements. Within the drink and fold menu movements can be activated directly. The cartesian and joint menu are subdivided into 4 submenus. These submenus have to be selected first (e.g. X1, J2), before a movement can be activated.

You can select a submenu by moving the joystick in the corresponding direction. By making a short, quick switch one can go up one level in the menu. E.g. when the control is in the submenu for Cartesian movements, the menu goes one up by making a short, quick switch. When this is repeated one ends-up in the main-menu.

Scheme joystick control



5 The single-switch control

5.1 The single-switch-control

The principle of the single-switch control is that all available operating functions of The ARM-unit can be operated with one and the same key. For the single-switch control the 4x4 matrix keyboard can be used, however every other single switch will function. Each key can be used to operate The ARM-unit.

The operating functions of The ARM-unit are placed in different *menu's*, which are marked with letters on the *display*. The menu's appear one at a time on the display, and a menu can be activated by pushing on the key as soon as the menu-letter appears on the display.

Within a menu a *submenu* can be defined (again marked with *letters*), or a set with available operating functions which are marked with *graphic symbols*. The symbols appear one at a time on the display, and the operating function wished for can be activated by pushing a key and hold this key until the corresponding graphical symbol appears.

Besides that it is possible to choose a different speed for The ARM-unit arm and a different scan-velocity for the display. The scan-velocity is a measurement for the velocity in which the symbols pass by on the display. *Errors and warnings* will reflect with *underlined letters*.

5.2 Starting The ARM-unit single-switch control

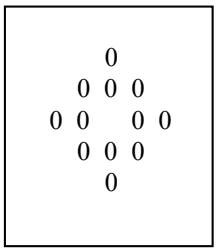
The ARM-unit can only be started when all system parts have been installed correctly. The following parts should be connected to the processor box:

- Power supply (wheelchair batteries)
- The ARM-unit arm
- Single switch
- Display-unit

According to the procedure shown below The ARM-unit can be started with the single-switch control:

- Turn the on/off switch in the on position, the on/of indication LED is turned on.
- Wait until The ARM-unit has installed itself; the gripper has opened and again partly shut.

The display shows during the starting procedure the symbol as shown below:



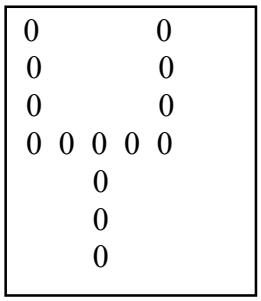
5.3 Using single-switch control

After the startup-cycle The ARM-unit will move to the main-control cycle. In this cycle the main menu will be scanned. This means that repeatedly new menu letters will appear on the display. A menu can be selected by pushing a key when the appropriate menu letter appears. Each menu consists of at least 1 movement-option. Movements can be selected by pressing the key. After pressing this key The ARM-unit will move. After releasing the key, the last selected movement will remain visible on the display for a short time, such that the user can choose the same movement again. This option enables users to position accurately by making short key presses. The menus in the main operating cycle are:

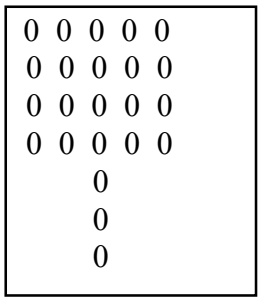
X : This menu handles cartesian control. It is divided into 2 submenus:

A : For control of the arm.
P : For control of the wrist.

In addition the symbols for gripper open/close are added to this menu.



Gripper open



Gripper close

The gripper open and gripper close movements stop after the key is released.

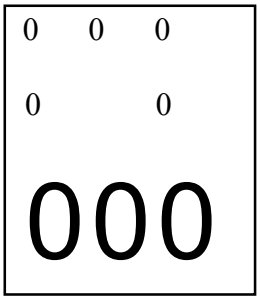
D : In this menu the controls for drinking can be found.

U : In this menu the controls for folding in or out, and the control of the high/low unit are categorised.

J : In this menu the joint-controls are categorised.

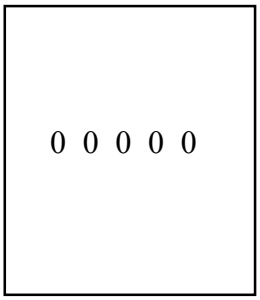
T : In this menu the scan-velocity (i.e. the velocity at which symbols change at the display) can be adapted.

S : In this menu the velocity at which The ARM-unit moves can be adapted.



All menus end with the symbol which is shown above. By activating this symbol the current menu will be left.

If for some time (30 symbols) no key is pressed, then the control will go to a pause state. This state can be recognised by the following symbol:

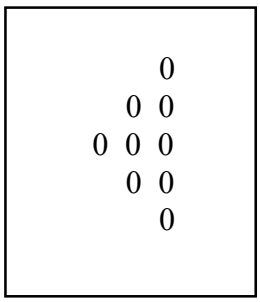


After pressing a key it is automatically started in the cartesian menu.

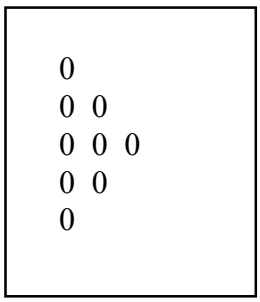
5.3.1 Operating menu for rectangular movements (X)

a. Operating menu for the arm positioning (A)

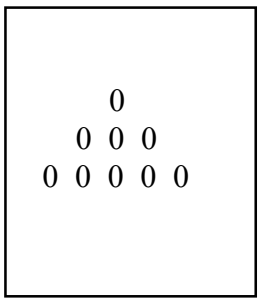
Within the A-submenu of the X-menu the following 6 menu-options can be found:



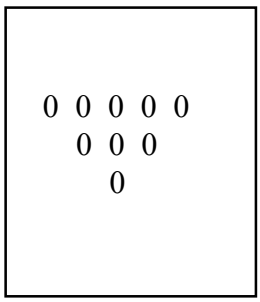
Symbol 1
Moving to the left of The ARM-unit.



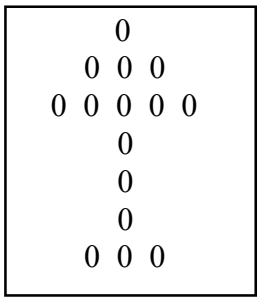
Symbol 2
Moving to the right of The ARM-unit.



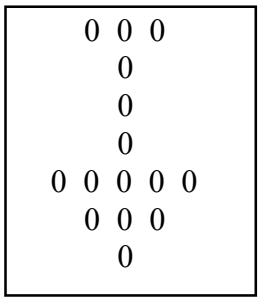
Symbol 3
Moving away from you



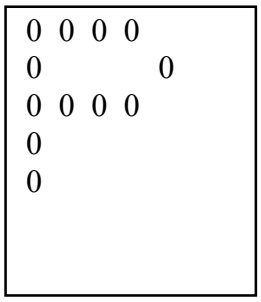
Symbol 4
Moving towards you of The ARM-unit



Symbol 5
Moving upwards of
The ARM-unit



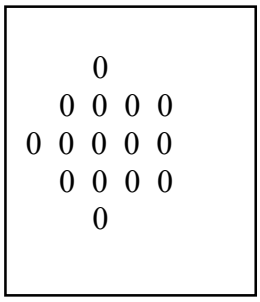
Symbol 6
Moving downwards
of The ARM-unit



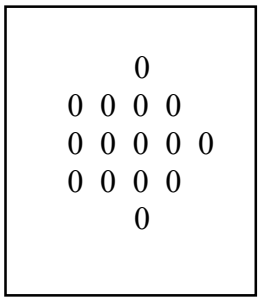
Symbol 7
to operating menu
for wrist movements

b. Operating menu for the wrist movements (P)

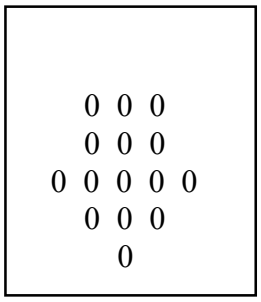
Within the wrist menu the following movement symbols can be found:



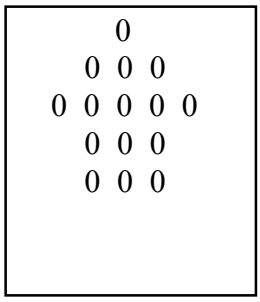
Symbol 1



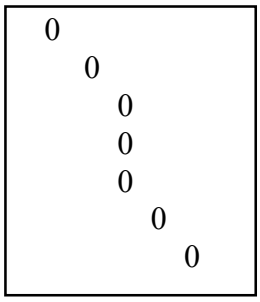
Symbol 2



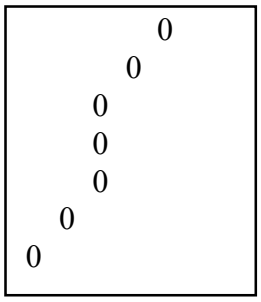
Symbol 3



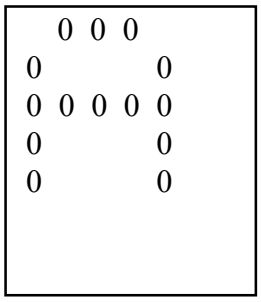
Symbol 4



Symbol 5



Symbol 6

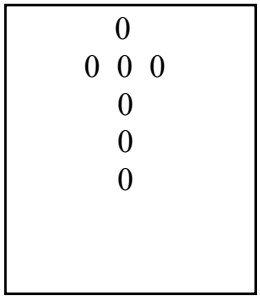


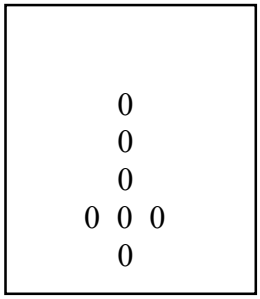
Symbol 7

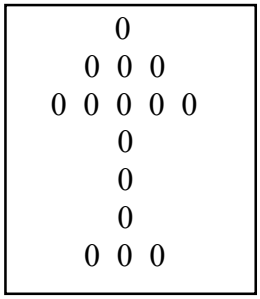
Symbol 1: Rotation to the right in the flat surface of the gripper of The ARM-unit.
Symbol 2: Rotation to the left in the flat surface of the gripper of The ARM-unit.
Symbol 3: Rotation upwards of the gripper of The ARM-unit.
Symbol 4: Rotation downwards of the gripper of The ARM-unit.
Symbol 5: Twist movement to the right of the gripper of The ARM-unit.
Symbol 6: Twist movement to the left of the gripper of The ARM-unit.
Symbol 7: Go to operating menu for arm positioning (X).

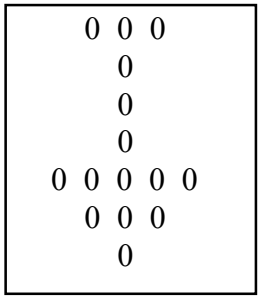
5.3.2 Operating menu for drinking (D)

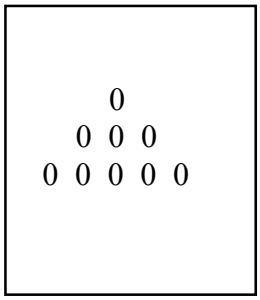
A special menu has been made with functions which facilitate drinking. These functions act on low velocity. The available functions in this menu are:

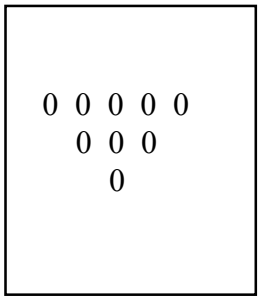

Symbol 1


Symbol 2


Symbol 3


Symbol 4

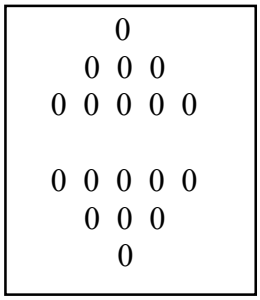

Symbol 5

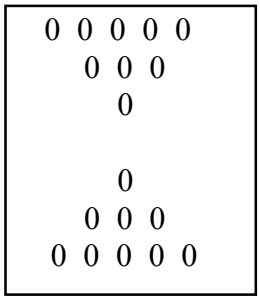

Symbol 6

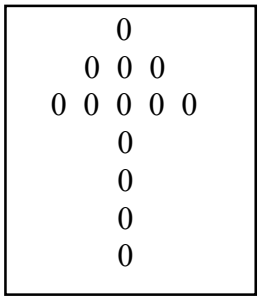
Symbol 1: Drinking movement towards you.
Symbol 2: Drinking movement away from you.
Symbol 3: Slowly moving upwards.
Symbol 4: Slowly moving downwards.
Symbol 5: Slowly moving away from you.
Symbol 6: Slowly moving towards you.

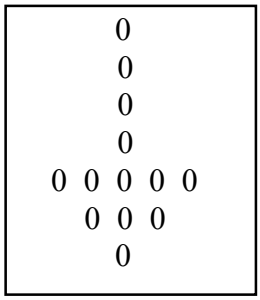
5.3.3 Menu for folding in and out (U)

The menu for folding in and out contains the symbols for folding The ARM-unit in and out, and for the operation of the high/low-unit. The symbols are:


Symbol 1


Symbol 2


Symbol 3

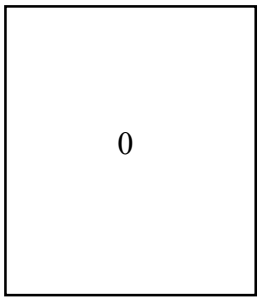

Symbol 4

Symbol 1: Folding out of The ARM-unit.
Symbol 2: Folding in of The ARM-unit.
Symbol 3: Moving upwards with the high/low unit of The ARM-unit.

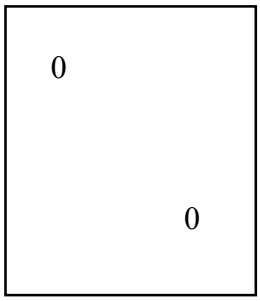
Symbol 4: Moving downwards with the high/low unit of The ARM-unit.

5.3.4 Control menu for joint movements (J)

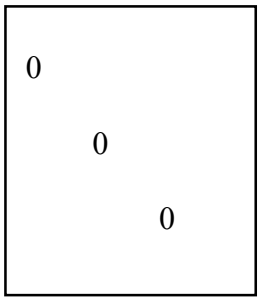
In the menu for joint movements you can aim for the shoulder, upperarm, forearm, wrist and gripper separately. After the menu for joint movements has been reached, the **J** symbol will appear on the display. The menu consists of 7 different symbols for each of the axles. These symbols are the eyes of the dice. After each passing movement for a certain axle, the symbol for the backward movement will appear of the same axle. The symbols are:



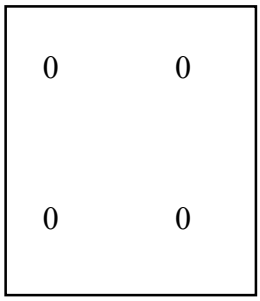
Symbol 1



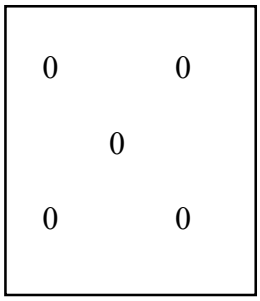
Symbol 2



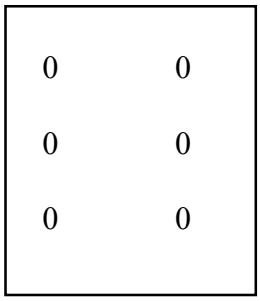
Symbol 3



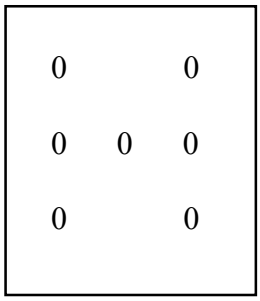
Symbol 4



Symbol 5

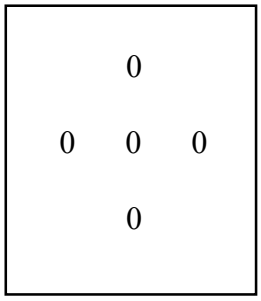


Symbol 6



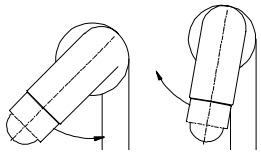
Symbol 7

The Symbol for the backward movement of each axle is shown as follows:

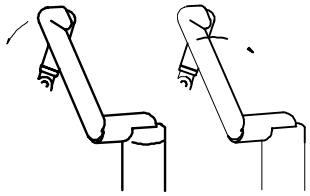


The different joint movements which correspond with the axis (symbols) are on the next page. The backward movement for each axis is shown in the second figure:

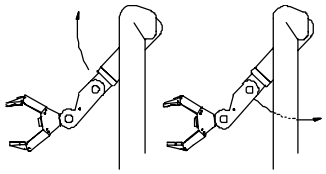
Symbol 1: Rotation axis 1.



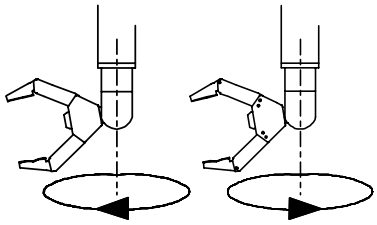
Symbol 2: Rotation axis 2.



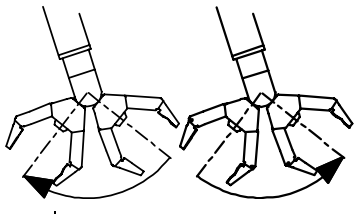
Symbol 3: Rotation axis 3.



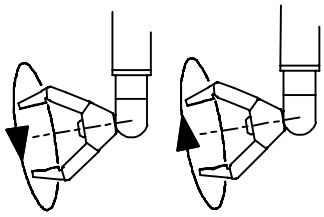
Symbol 4: Rotation axis 4.



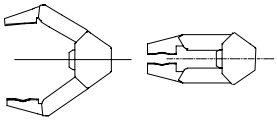
Symbol 5: Rotation axis 5.



Symbol 6: Rotation axis 6.



Symbol 7: Rotation axis 7:



WARNING

Using the ARM in joint menu may cause serious damage to the ARM itself, because in the joint menu no “prohibited areas” are defined, which impede the gripper from colliding with the ARM.

5.3.5 Menus for adapting scan-velocity (T)

In the T-menu the scan-velocity can be adapted. The following possibilities are present:

1 : Every 1,75 second a new symbol appears.
2 : Every 1,5 second a new symbol appears.
3 : Every 1,25 second a new symbol appears.
4 : Every 1 second a new symbol appears.
5 : Every 0,75 second a new symbol appears.
6 : Every 0,5 second a new symbol appears.

When starting up the scan-velocity will be adapted on 0,75 seconds (position 5).
In case a new scan-velocity is chosen, the operation will automatically move on to the main menu.

5.3.6 Menu for adapting the velocity of The ARM-unit (S)

In the S-submenu velocities can be adapted by pushing a key as soon as the symbols pass by. For this applies:

> : Means low velocity.
>> : Means high velocity.

When starting up the velocity will be adjusted at the low velocity.
In case a new velocity is chosen, the operation will automatically move on to the main menu.

5.4 Errors and warnings of the single operating function

In The ARM-unit surroundings a distinction has been made between warnings and errors. In case of a warning certain movements will not be possible anymore, however The ARM-unit will still be functioning. In case of an error The ARM-unit will not be functioning anymore. Usually a last report will be left on the display.

5.4.1 Warnings

The ARM-unit knows a number of warnings. In the case of a warning a warning symbol will variously appear. The warning symbol often reflects underlined. A beep can also be heard. You can often get in a warning situation by moving in the opposite direction.

5.4.2 Errors

Furthermore The ARM-unit has some error messages. In case of an error message The ARM-unit has to be switched off. It is most wise to try to repair The ARM-unit by repeatedly switching the system on and off. In case of continuing error warn your local distributor.

WARNING  If the ARM is switched off, any object which is in the gripper will be released and will fall out. Remove any object from the gripper, before switching the gripper off.

6 The PC-CAN-Control (Transparent mode)

This chapter describes the installation and use of the *transparent mode* for the Manus ARM robotmanipulator.

6.1 Controlling the Manus ARM by a PC through CAN-bus

The transparent mode for the Manus ARM robotmanipulator allows you to control the movements of the Manus ARM by an IBM compatible PC. The PC and Manus ARM communicate through a CAN-bus (Controller Area Network). It is a bus for serial communication, developed by Bosch, supports distributed real-time control systems with a high safety level.

Tow types of CAN busses exist: basicCAN and fullCAN. The transparent mode applies basicCAN bus, which is supported by the Philips CAN controller PCA 82C200. This bus consists of three wires: Ground, CAN+ and CAN-. The baudrate on this bus is 250 Kbits/sec. For more information on CAN buses, please refer to

`http://www.caninfo.com`

It is not possible to simultaneously use the transparent mode and another input device (like a keypad of joystick) to control the ARM. In the case you want to be able to flexibly select an input device (transparent mode, keypad, joystick) and use this device to control the ARM, you must obtain a so called *software selector box*.

6.2 System requirements and technical specifications

Installing the transparent mode requires and IBM compatible PC with at least one free 16-bit ISA slot and MS-DOS, Win 3.x or Win9x as a operating system.

CAN-controller:	82C200
Base address CAN-card:	0x300
Bus CAN-card:	16-bit ISA
Bus type:	BasicCAN
Baudrate CAN bus:	250 kbit/s
Power supply	PC
Operating systems:	MS-DOS, Win 3.x, Win9x
Language example source file pccan.c:	ANSI C

6.3 Safety

Safety is essential! Read the following section carefully and follow the cautions and warnings that are placed throughout this manual.

WARNING  If the actions indicated below and throughout this section are not complied with, serious injury to you could result as well as major damage to the ARM.

When the ARM is controlled by standard input devices like a keypad or joystick, several safety features and safety checks are carried out by the computer box. In the case of transparent mode, two safety issues require special attention of the user. These three safety issues are discussed below.

1. Once the ARM is executing a command, which is issued by the PC through the CAN-bus, it will continue the executing of this command until another command is issued. For example, if you send a speed command for axis 1, the ARM will continue to move axis 1 until you send a different speed command for axis 1. Hence, to stop axis 1 (e.g. to prevent a collision) you explicitly need to send a speed command with value 0.

2. Using standard input devices like the keyboard and joystick, speed of the ARM in Cartesian mode is limited to 25 cm/s, and to 12 and 30 degrees/s in case of joint mode. The transparent mode allows higher speeds of the ARM in Cartesian as well as in joint mode. Therefore, at high speeds, special precautions should be taken to prevent collisions, with persons, objects in the envelope of the ARM, as well as with the ARM itself.

3. In contrast to a standard input device, it is possible to control more than one axis of the Manus ARM simultaneously, i.e. you can control two or more axis (*x, y* and *z*) in Cartesian mode simultaneously, you can control two or more axis (axis 1 to axis 7) in joint mode.

6.4 Contents transparent mode kit

The transparent mode kit consists of:

- Combined power/CAN cable,
- an EEPROM with software for the 552 processor inside the computer box. If you ordered ARM including transparent mode, this EEPROM is installed in the computer box. If you ordered the transparent mode separately you have to install the EEPROM yourself (see section 6.5.1),
- 1 floppy disk (3.5") containing transparent mode demo software (pccan.exe and pccan.c)
- 1 PC-CAN interface card

If one or some of these items are missing, please contact Exact Dynamics.

Note: Any third party CAN interface card can be used to control the ARM. However, in that case to need to write your own driver, matching the protocol as described in section 6.7.

6.5 Hardware installation

6.5.1 Installation of the EEPROM

If you ordered ARM including transparent mode, the EEPROM has already been installed in the computer box and you can skip this sub-section and proceed with sub-section 6.5.2 *Installation of the PC-CAN card.* If not, take the following steps to install the EEPROM:

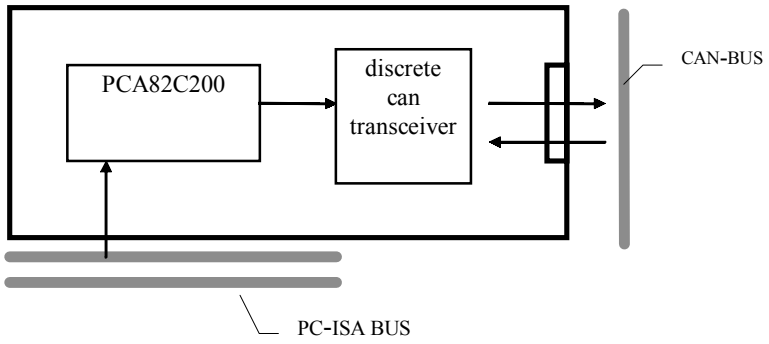
1. Turn off the Manus ARM
2. Disconnect the computer box of the Manus ARM from the power supply and all peripheral devices,
3. Replace the 552 EEPROM on the printed circuit board by the EEPROM marked 552.1 provided in the transparent mode kit,
4. Close the computer box Manus ARM and reconnect all peripheral devices.

6.5.2 Installation of the PC-CAN card

Once the correct EEPROM in the computer box Manus ARM has been installed you can install the PC-CAN card in your PC. For more information please refer to the manual of your PC.

1. Ground yourself by touching the power unit casing,
2. Turn off your PC and all peripheral devices. Disconnect the PC from the power supply and all necessary components,
3. Loosen the PC's cover screws and remove the cover,
4. Select a free ISA/PC-XT slot. Remove the slot's cover at the back of the PC,
5. Carefully insert the PC-CAN card into the ISA slot by holding the card at the top and gently pushing both ends into the slot at the same time,

Figure 6.1: *PC-CAN card*



6. Fasten the card's bracket at the back of the computer,
7. Replace the cover of the PC and fasten its cover screws

The CAN card is powered by the PC.

6.5.3 Connecting the CAN-cable

Finally, you have to connect the cables:

1. Connect the CAN cable to both the combined power-CAN cable of the Manus ARM and CAN-card mounted in the PC,
2. Turn on the PC,
3. Turn on the Manus ARM.

The pin configuration of the 9-pins D-sub connector on the PC-CAN card is:

Pin	Signal
3	GND
6	CAN+
9	CAN-

The CAN cable is not galvanically disconnected/separated from the CAN card.

6.6 Software installation

Take the following steps to install the transparent mode demo software on your PC:

1. Create a new directory on your PC's hard disk
2. Copy the all files on the floppy disk provided to this new directory on your hard disk,
3. Execute the program **`pccan.exe`** on your hard disk. A help screen appears. The Manus ARM can now be controlled by the appropriate keys on the keyboard of your PC.

The demo program is a 16-bit DOS application. The program will only run with the PC-CAN card provided by Exact Dynamics. If you apply a third party PC-CAN card you have to adapt/modify the source code of the file **`pccan.c`** on you hard disk and compile it, or write your own driver. For more information on the use of the demo program and structure of the source code **`pccan.c`**, see section 6.11.

The base address of the CAN-card is **`0x300`**, which can not be changed. The card dos not support interrupt programming. For details please refer to the source code file **`pccan.c`** provided.

6.7 The control structure of the ARM

The control system of Manus ARM consists of three micro processors, see Figure 6.2.

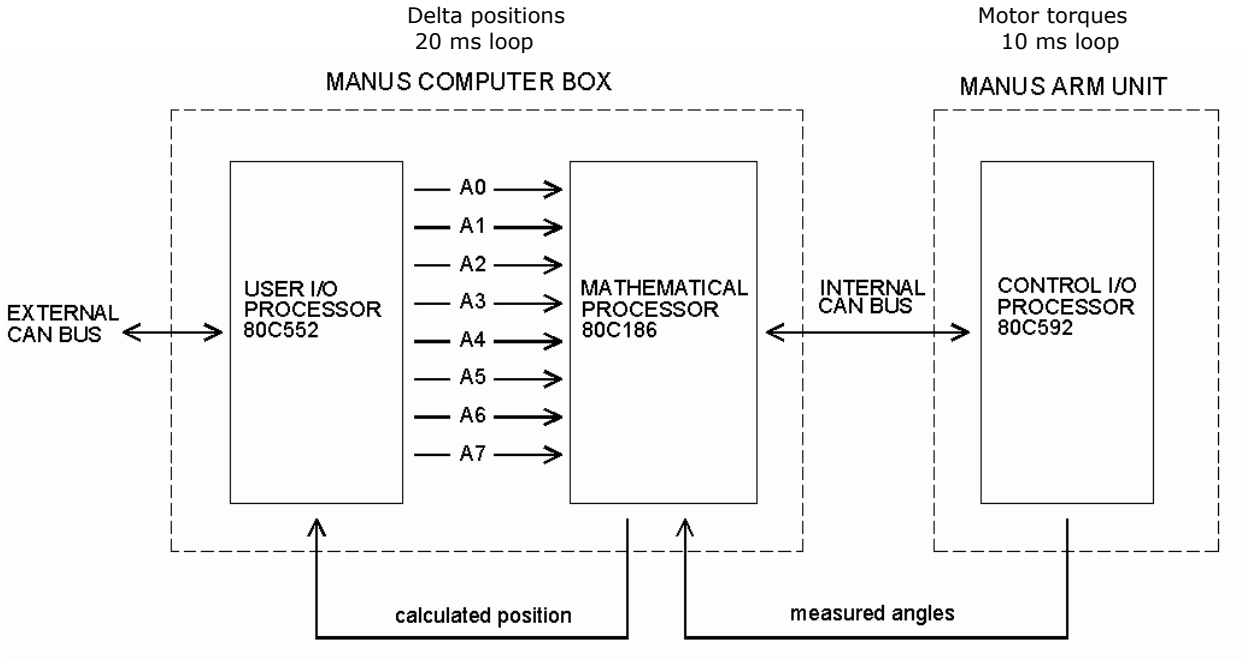


Figure 6.2: The control structure of the Manus ARM consists of three processors.

The main processor is a Intel 80C186 processor and is referred to as the *Mathematical processor*. This processor handles safety checking, co-ordinate transformations (in Cartesian mode) and calculates the required motor torques via a PI-controller based on velocity inputs. The set points of the mathematical processor are received from the second processor, which is a 80C552 microcontroller, and is referred to as the *User I/O processor*. This processor processes the user input. The calculated torque set-points from the 80C186 are send to the third processors, which is a 80C592 microcontroller and is referred to as the *Control I/O processor*. This processor is located inside the Manus ARM. The communication between the *User I/O processor* and the *Control I/O processor* runs also through a CAN-bus, and is referred to as the *Internal CAN bus*. The protocol and connection of this bus is handled by the a Philips 82C200 chip.

The *Internal CAN bus* should not to be confused with the CAN bus between the computer box and your PC. The latter is referred to as the *External CAN bus* and is used to send commands from the PC to the *User I/O processor* (and vise versa). It is not possible to connect the PC via the CAN card directly to the *Internal CAN bus*. For simplicity, the *External CAN bus* will also be referred to as the *CAN bus*, in the following.

Communication on the CAN bus

Information on the CAN-bus is send as a package, consisting of:

- the identification (ID) of the package,
- a flag which indicates whether information is or is not retrieved (rtr) and,
- the length of the package (number of bytes)
- eight bits of data

Parameter	Data type	Example
ID	hexadecimal number	350, 37F, ...
rtr	Flag	0 or 1
len	Number	0... 8
data	8 bits	11011100

The controlbox (cbox) concept

When controlling the ARM using transparent mode a so called *control box* (cbox) or mode has to be selected. Five control boxes exist:

Control box	Mode
cbox0	Start-up/initialization mode
cbox1	Carthesian control
cbox4	Joint control (degree of freedom control)
cbox6	Folding in
cbox5	Folding out

In each control box, the user inputs are treated in a different way, see Figure 6.3.

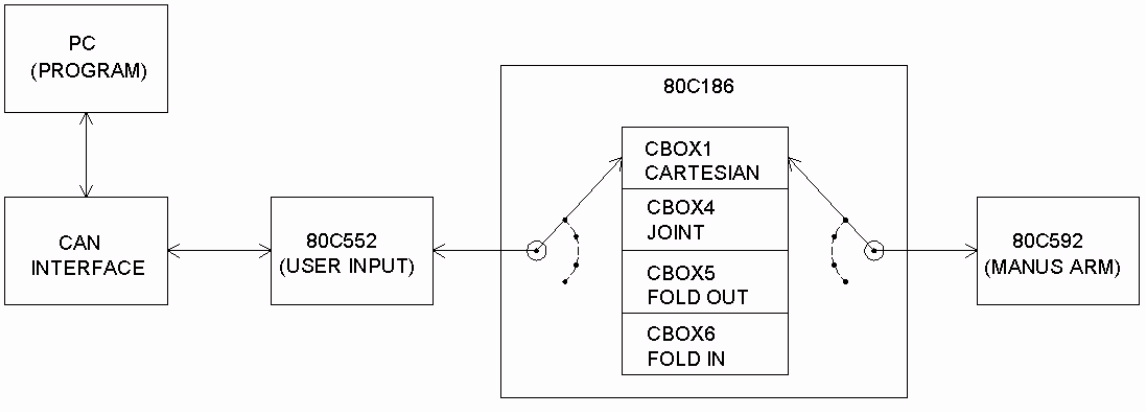


Figure 6.3: The concept of control boxes.

After start up the Manus ARM is in the initialisation mode (cbox0). Next, a other controlbox can be selected. The selected control box determines the way user in/out is interpreted by the mathematical processor. It also determined the meaning of (position) feedback information.

6.8 Programming the ARM via CAN bus

The Manus ARM can be controlled, by sending the appropriate commands from the PC via the *External CAN-bus* to the *User I/O processor* (80C552 microcontroller). This microcontroller just trans-

fers the commands directly to the *Mathematical processor* (80C186 microprocessor). In addition it activates symbols on the display.

The communication between the the PC-CAN card and the *User I/O processor* is according to a question & answer protocol. The *User I/O processor* sends a package to the PC-CAN card every 20 ms. First, two information packages are send. The third package asks for a response from the PC. Hence, the PC can supply commands to the Manus ARM every 60 ms. However, it is not required to respond to the request with an answer. The answer is requested for only for synchronization purposes. If you do provide answer it overrules (overrides) commands send earlier. When no answer is provided prior send packages and parameters (commands) remain active. The table below gives an overview of all commands/packages:

INFO 552			**ANSWER PC**			**Description**	**Contents of package**
ID	rtr	len					
350	0	8	no answer!!			2 status bytes	Warning, Error, or fold status
			Read message!			Orientation of axis 1 to 3	6 bytes: MSB and LSB of axis 1 to 3
360	0	8				Orientation of axis 4 to 7	8 bytes: MSB and LSB of axis 4 to 7
QUESTION 552			**ANSWER PC**				
ID	rtr	len	ID	rtr	Len		
37F	1	0	370	0	0	Selection of cbox0	Free
			371	0	8	Selection of cbox1	Desired displacement of axis 0 to 7
			374	0	8	Selection of cbox4	Desired displacement of joint 0 to 7
			375	0	0	Selection of cbox5	Fold out
			376	0	0	Selection of cbox6	Fold in

The timing of an answer is not critical. Be aware that you first have to select a control box, before you can send any movement command. So if you are in start-up mode (cbox0), and you want to make Cartesian movements, you first have to go select cbox0 (Cartesian mode). After this you need a second command to activate Cartesian movements. Speed values in a package selecting a control box (cbox) are ignored.

Example

The communication between the PC and the Manus ARM could for example look like:

Time (ms)	**Communication**
20	The 80C552 sends a package with ID 0x350. Just read or interpret.
40	The 80C552 sends a package with ID 0x360. Just read or interpret.
60	The 80C552 sends a package with ID 0x37F;Give me the control box and desired movements!
60	Answer with 0x371, all bytes 0; Go to cartesian mode, stand still.
80	The 80C552 sends a package with ID 0x350. Just read or interpret.
100	The 80C552 sends a package with ID 0x360. Just read or interpret.
120	The 80C552 sends a package with ID 0x37F; Give me the control box and desired movements!
120	Answer with 0x371, second byte=1. Remain in cartesian mode, move along *x*-axis with speed 1.

6.8.1 Cartesian controlbox (cbox1)

In control box 1 (cbox1) the Manus ARM can be positioned along its *x*, *y* and *z* axis. When this control box is active the display will show an "X". Position commands send by the PC to the *User I/O processor* are sent to the *Mathematical processor*. The table below shows valid position commands.

POSITION COMMANDS				
Byte no.	**Parameter**	**Increment(s)**	**Minimum**	**Maximum**
1	(A0) LIFT UNIT	Up/off/Down -1 0 1	-1	1
2	(A1) X	0.022 [mm]	0 [increments]	127 [incr.]
3	(A2) Y			
4	(A3) Z			
5	(A4) YAW	0.1 [degree]	0 [incr.]	10 [incr.]
6	(A5) PITCH			
7	(A6) ROLL			
8	(A7) GRIPPER	0.1 [mm]	0 [incr.]	15 [incr.]

Example

If the value of byte number 2 is set to 10, the ARM will move 0.22 mm (=10×0.022mm) after 60 ms. If, after this, this byte is not changed (so no new or the same package is send) the ARM will move with a speed of 0.22 mm per 20 ms. This is due to the fact that this information (send by the PC) is send by *User I/O processor* to the *Mathematical processor*, every 20 ms.

The maximum opening between the fingers of the gripper is 90 mm. After the gripper is closed, or the two fingers have grasped an object, a spring in the lower arm is extended, resulting in a built up of the gripper force. While building up the gripper force, the distance between the fingers of the gripper does not change linearly, according to the table above.

6.8.2 Joint controlbox (cbox4)

In control box 4 (cbox4) the individual axis of the Manus ARM can be rotated/operated. In cbox4 the display shows a "J". Position commands send by the PC to the *User I/O processor* are sent to the *Mathematical processor*. The table below shows valid position commands.

POSITION DISPLACEMENTS				
Byte no.	**Parameter**	**Increment(s)**	**Minimum**	**Maximum**
1	LIFT UNIT	Up/off/Down -1 0 1	-1	1
2	A1	0.1 [degree]	0 [incr.]	10 [incr.]
3	A2			
4	A3			
5	A4	0.1 [degree]	0 [incr.]	10 [incr.]
6	A5			
7	A6			
8	GRIPPER	0.1 [mm]	0 [incr.]	15 [incr.]

The response of the gripper to position command is identical to its response in Cartesian mode (see previous section).

WARNING 

In the Joint controlbox (cbox4), the *Mathematical processor* does NOT perform safety checks to prevent a collision of the gripper with another part (e.g. upper arm or base) of the ARM. You should therefore generate a collision free path for the gripper! A collision may result in major damage to the gripper or other parts of the ARM.

6.8.3 Folding out controlbox (cbox5)

In order to be able to fold out the ARM has to be folded in. The current fold status can be requested for. During fold out you can stop and continue.

The ARM will only fold out if the cbox5 is selected twice. With the first command you enter the fold out control box (cbox5). Sending the second command starts the fold out sequence. During folding out the display will show the symbol shown in Figure 6.4.

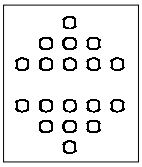


Figure 6.4: Symbol shown on the display in control box Folding out (cbox5)

The ARM folds out according to a pre-programmed path, with a fixed velocity, which can not be changed. At the end of the fold out procedure, the "unfolded" status is return by the *User I/O processor*.

6.8.4 Folding in controlbox (cbox6)

The ARM will only fold in if the cbox6 is selected twice. With the first command you enter the fold in control box (cbox6). Sending the second command starts the fold in sequence. During folding in the display will show the symbol shown in Figure 6.5.

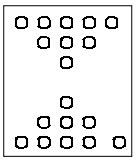


Figure 6.5: Symbol shown on the display in control box Folding in (cbox6)

The ARM folds in according to a pre-programmed path, with a fixed velocity, which can not be changed. The only control you have is to continue or stop folding in.

6.8.5 Position feedback

In the Cartesian control box (cbox1) and Joint control box (cbox4) the position of the ARM is send by the *User I/O processor* to the PC. In Cartesian control box (cbox1) the position is defined in Cartesian

coordinates. In Joint control box (cbox4) the position is defined in joint coordinates (angles).

As explained before, the *User I/O processor* first sends two information packages, at t=20ms and t=40ms. These information packages should be interpreted as follows:

ID	Byte no.	Value	cbox1	cbox4
0x350	1	Movement error	Status	status
	2	Blocked DOF	message	message
	3	MSB	X	axis1
	4	LSB		
	5	MSB	Y	axis2
	6	LSB		
	7	MSB	Z	axis3
	8	LSB		
0x360	1	MSB	Yaw	axis4
	2	LSB		
	3	MSB	Pitch	axis5
	4	LSB		
	5	MSB	Roll	axis6
	6	LSB		
	7	MSB	gripper	gripper
	8	LSB		

The identifier (ID) of the package determined how the remaining bytes of the package should be interpreted.

Of the package with identifier 0x350, the first 2 bytes provide the status of the ARM. Byte 1 determines whether the package contains a *message*, *warning* or *error*. Byte 2 determines which status, warning of error message it is, see section 3.3. The remaining bytes (3 to 8) give position information, consisting of a MSB (Most Significant Byte) and a LSB (Least Significant Byte):

Byte x: MSB of the position
Byte x+1: LSB of the position

The combined value of these two bytes provides the position in increments, see section 6.8.1 and section 6.8.2.

Example

Suppose the *User I/O processor* has send to followng package to the PC, while in Joint control box (cbox4):

ID	Byte 1	Byte 2	Byte 3	Byte 4	Byte 5	Byte 6	Byte 7	Byte 8
0x350	1	3	11	14	7	3	5	6

This package should be interpreted as follows:

- Byte 1 has the value 1, indicating a warning message,

- Byte 2 has the value 3, indicating that the warning concerns a blocked motor,
- Byte 3 & 4 contain the position of axis 1. The value of these bytes are 11 (MSB) and 14 (LSB) respectively. So the current orientation of axis 1 is $(11\times 256 + 14) \times 0.1° = 283°$
- Byte 5 & 6 contain the position of axis 2. The value of these bytes are 7 (MSB) and 3 (LSB) respectively. So the current orientation of axis 1 is $(7 \times 256 + 3) \times 0.1° = 179.5°$,
- Byte 7 & 8 contain the position of axis 3. The value of these bytes are 5 (MSB) and 6 (LSB) respectively. So the current orientation of axis 3 is 128.6°.

6.8.6 Tips & tricks for advanced users

Velocity behavior of the ARM

Carefully analyzing the control method of the ARM using transparent mode shows that the *Mathematical processor* is controlling the ARM on the basis of a velocity input. That is user *position* input (e.g. a value of p mm) from the *User I/O processor* is added to the 'desired position' of the ARM every 20 ms. Hence, defining which is in fact a velocity $v=p/20\cdot10^{-3}$ mm/s. The PI-motor-controllers ensure that the ARM moves at this specified (reference) velocity (input). If you do not change the value of this position p, this desired displacement is added in time on the desired position, resulting in a constant displacement in time, which is in fact velocity.

This "velocity" behavior of the ARM changes when the specified velocity $v=p/20\cdot10^{-3}$ mm/s can not be reached, e.g. when this specified velocity is too large. In that case, the difference between the actual position and the position to be reached increases. This difference is known as the *position error*. If the position error increases, the motor torques are increase in an attempt to reduce the position error. As a result the velocity of the ARM increases reducing the position error. Hence, the velocity of the ARM is no longer equal to the "specified" velocity.

Also when a joint is blocked (e.g. due to an obstacle) the position error increase, and as a result the motor torque increases. Then, if the blocked joint is released, the ARM moves at increased velocity in an attempt to reduce the position error as fast as possible.

WARNING 

Removing the user inputs by selecting cbox0, before the joint is able to move again does not solve this problem. It will result in the so called *Move Without Input'-error (M)* and will result in a software deadlock of the microcontrollers (Figure 6.2). You should command the joint to move in the opposite direction, which reduces the (absolute) position, to safely recover from a blocked motor situation.

Point-to-point control (position control)

Point to point control is applied in practice and gives satisfactorily results, but you should be aware of the following difficulties.

Backlash

The Manus ARM shows some mechanical backlash in its transmissions. As the angles of the joints are measured on the motor axis (and not on the joints), the measured angles of the motor may not represent the actual angles of the joints. As the exact magnitude of the backlash is unknown it is not possible to calculate the exact location (angles) of the joints from the measured angles of the motors. Hence, if for example 1 [increment] is send to the ARM, the joint might not move due to mechanical backlash.

Friction

Also friction in the transmissions may impede the ARM from moving when small displacements are commanded (e.g. 2 increments). If the commanded displacement is small the position error will be small. As a result the motor torques may be too small to overcome friction, and the joint does not move. The ARM might start moving when, for example, 10 increments are commanded. In that case the joint may shows overshoot (.e.g. 15 increment) when it is suddenly able to overcome friction.

Speed behavior

A second issue to consider, when implementing point-to-point control is the speed behavior of the controller of the ARM, as discussed above. The position loop of the controller contains a proportional action only, whereas the speed loop contains an integral action in addition to the proportional action.

6.9 Status clarification

The first 2 bytes of a package with identifier (ID) equal to 0x350 represent the status of the ARM.

A status is categorized as either *warning*, *error* or *general messages*. The first byte (Byte 1) indicates the message *type*, the second byte (Byte 2) contains the message itself. When the first byte is equal to 0, implies “no message” and the second byte should be ignored. The table below gives an overview of warnings, errors and general messages.

Byte 1	Message type	Byte 2	Description
0	No message	X	(not defined)
1	Warning	0	Gripper stuck. The gripper has collided with other parts of the ARM. Move the gripper in the opposite direction.
		1	Wrong area.
		2	Arm folded is folded, and you try to fold it even more. Or the ARM is fully stretched, and you are attempting to stretch it further. Move the ARM in the opposite direction.
		3	Blocked motor. The load is too heavy blocking a motor, or you are pushing against an object, impeding the ARM to move. Reduce or remove the load, or move in opposite direction.
		4	Maximum M1 rotation. Move in opposite direction. A "Maximum M1 rotation" warning will occur in older ARM versions, which show a limited rotation of axis 1. ARM's with serial number 98.04.01.XX or higher, which are black, have no rotation limitations on axis 1.
2	General Message	0	Folded
		1	Unfolded
		2	Gripper is ready initializing
		3	Absolute measuring is ready
3	Error	0	'E' error.
		1	I/O 80C552 error
		2	'E' error.
		3	'E' error..
		4	Absolute encoder error
		5	(not defined)
		6	'E' error..
		7	'E' error.
		8	'E' error.
		9	(not defined)
		10	(not defined)
		11	'E' error.
		12	'E' error.
		13	'E' error.
		14	(not defined)
		15	Move without user input error, see section 6.8.6.

6.10 PCCAN.EXE

The transparent mode of the Manus ARM comes with a demo DOS program **`pccan.exe`**. It is a 16-bit DOS application. Its source code **`pccan.c`** is also provided (see next section).

Once the program **`pccan.exe`** has been started, the following commands are available:

```
'?' for help
'q' for quit
'p' for printing of the positions in
actual controlbox
'0' for mode switch
'1' for cartesian control
'2' for set zero
'4' for joint control
'5' for fold out
'6' for fold in

'q/a' for A1 or X (depending the mode)
'w/s' for A2 or Y (depending the mode)
'e/d' for A3 or Z (depending the mode)
'r/f' for A4 or yaw (depending the mode)
't/g' for A5 or pitch (depending the mode)
'y/h' for A6 or roll (depending the mode)
'u/j' for gripper open/close (A7)
'z/x' for lift unit up/down (A0)
```

Pressing any other key will stop movements (except fold in/ fold out)

6.11 PCCAN.C

The program **pccan.exe** will only run with the PC-CAN card provided by Exact Dynamics. If you apply a third party PC-CAN card you have to adapt/modify the source code of the file **pccan.c** and compile it, or write your own driver.

The source code starts with all the definitions of the addresses of the CAN chip,. Next, the controlboxes, warnings and eventually the maximum and minimum increments of displacements, are defined. Then the structure of a package is defined, consisting of an ID, a retrieve bit (rtr), a length indicator (len) and the bytes containing the actual command/parameter.

The main sub-routine is in an endless loop, consisting of receiving, decoding, transmitting and reading the PC keyboard.

In the decode procedure, a switch structure, based on the ID of the package, is used to decode a package. If the ID equal 0x350, the status of the ARM is evaluated (Gripper ready/Absolute angles ready.) Next the Most Significant Byte (MSB) and the Least Significant Byte (LSB) are read, representing the angles of axis 1, 2 and 3. If the ID equals 0x360, the LSB and MSB represent the angles of axis 4, 5 and 6. If the ID is not equal to 0x350 or 0x360 the package is decoded using a switch structure based on the active control box (cbox) of the ARM. In Joint and Cartesian mode, the desired rotations/displacements are copied, into the returning message as speed. If a certain value of desired rotation of a given axis is kept constant, then this results in a desired speed = constant displacement in time.) In case of the Fold Out mode (cbox5) or the Fold in mode (cbox6) only the ID of the package is defined.

The next routine displays the status on the screen, reads the status of the PC keyboard and prints help on the screen.

In the function CANINIT then 82C200 CAN chip from Philips is initialized For details is referred to the data sheets of the replacement of this chip: SJA1000.

The transmission routine codes the message, its length, the ID, and the retrieve flag (rtr) into two bytes (LSB and MSB). In the MSB the ID of the message is stored. The variable **`ident`** is divided by eight to fit in the range of a byte, e.g. 0x350 > 0xFF, but 0x350/8=0x6A. In the LSB a part from the identity is stored, along with the retrieve semaphore and the length of the message. Next, a counter in the code limits the time to wait for the CAN chip to be ready to send the message. If the this chip is ready in time, the two bytes mentioned above are sent to the CAN chip and directly afterwards the actual data of the message and the command to sent the package over the bus.

The receive routine works similar.

6.12 FAQ (software)

Frequently Asked (software) Questions are:

Q: When Manus turns into an error state, a solution is to reboot the Manus computerbox. Is there another solution?
A*:* No, in an error state Manus computerbox needs to be rebooted manually.

Q: Do I have to set up a request to Manus, before I am able to send him commands?
A*:* No, after the computer of Manus has been powered on, questions form the 80C552 processor will automatically appear on the CAN bus.

Q: What does ‘A0’ mean?
A: A0 is the control of the optional lift unit of the ARM. An input of ‘-1’ means: the lift unit goes to lower position, ‘0’ lift unit stops moving, ‘1’ the lift unit goes to higher position.

Q: Why must I send the foldin command twice to fold the ARM?
A: The first command is to enter the fold in control box, the second command is used to activate the ARM to folding in. This has to be done for every change of controller box.

Q: Why does Manus keep on moving without sending input over the CAN bus?
A: The user input is not automatically reset by the 80C552. Cbox0 needs to be selected to reset al the inputs, or speed 0 has to be commanded for all inputs.

Q: Why does Manus keep on moving after selecting cbox0?
A: When selecting cbox0, all user inputs will be reset. For this reason, position errors will not increase anymore. However, an

existing position error will not be set to 0. These results in non zero torques on the motors, hence the ARM is moving.

Q: The ARM does not fold in, why?

A: Folding in is not allowed in the prohibited area as described in the *The ARM User's manual*. This situation is indicated by a warning, see section 3.4. The orientation of the ARM must be changed manually, or by PC control in the Cartesian or Joint mode.

Q: What happens if the user input exceeds its maximum?

A: Too big user inputs may lead to increasing position errors. The PI-controller will not be able to reach the desired speed. As a result, Manus will continue moving after this user input is set to 0. You should prevent this situation, as the behavior of the manipulator becomes un-predictable.

7 Customer services

When there are problems with The ARM-unit or if you have questions, please contact Exact Dynamics.

7.1 Service contract

An annual service contract for the ARM can be bought from Exact Dynamics. This service contract can be prolonmged each year to a maximum of 5 years. When closing such a contract The ARM-unit will be serviced and repaired (assembly faults) for free. The service contract includes a 8 hours helpdesk support per year. You have to send The ARM-unit to Exact Dynamics once per year for maintenance. On the next two pages the standard maintenance activities are listed, which will be executed (standard activities are activities that directly influence the continuance of good functioning of The ARM-unit manipulator).

CHECKLIST EXECUTED MAINTENANCE ACTIVITIES:

Initial activities:

- yearly planning/interim planning
- check-in of The ARM-unit and determine the completeness of provided information
- determine the actual technical condition of The ARM-unit
- analysing possible errors/faults
- if necessary discuss this analysis and remarks from other end-users with you

Mechanical maintenance The ARM-unit basic:

Checking the good functioning and/or condition and/or excessive wear and, if useful or necessary, cleaning and/or providing with new grease and/or replacing and/or adjusting of:

- A1-bearing
- belts in column, lower arm, wrist and A1-axis
- tolerance and grease in reduction box
- couplings
- all fastenings
- absolute encoders
- CCD-arrays
- bevel gears wrist
- bevel gears elbow
- tension of belt (upper arm and wrist)
- long gripperband (wrist side)
- A1-drivebelt
- gripper
- total cleaning (excl. external cleaning due to use, see art. 6.g. maintenance
- contract)
- taking apart lower arm, cleaning the conductors and provide with new grease

- remove rust and if possible treat anti-corrosive

Mechanical maintenance lift-unit:

- taking apart the complete unit
- dry cleaning of the parts
- checking the condition of the bearings, if necessary setting new bearings, and provide with new grease
- checking the condition of the spindle and provide with new grease

Software maintenance:

If desirable and possible:

- upgrading system-software

Electronical/electrotechnical maintenance:

Checking good functioning of and, if useful and necessary, cleaning and/or replacing of:

- main cable/all cables
- keyboard and display unit
- cable connections
- components

General:

- Testing total system on good functioning
- maintenance reporting
- preparing transportation
- Helpdesk support (telephone, max. 8 hours per year)

7.2 Questionnaire for repair of The ARM-unit

To get a clear picture of the problems which could occur with The ARM-unit, we have drafted this form. This way it will be possible for us to execute repair quicker and with more efficiency. For this reason it is necessary for you to answer the questions well-defined, so that we will have as many information as possible which is important for the repair.

Thank you in advance,
Exact Dynamics b.v.

A. GENERAL

1. The ARM-unit number :----------
2. Date :----------
3. What problems do you have?

4.a) What have you tried yourself to solve these problems?

4.b) Did you use the manual to find a solution?yes/no
4.c) Have you had these problems before? yes/no
4.d) If yes, how many times was The ARM-unit returned for this? ... times

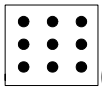
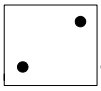
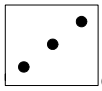
5. Did a problem situation occur before the problems showed up (for example collision, a fall, driving in the rain)?
   - o yes: ----------
   - o no

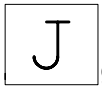
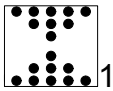
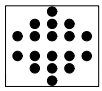
B. CONDITION OF THE ARM-UNIT

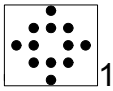
1. How is the present condition of The ARM-unit?
1.a) Does The ARM-unit still start up? yes/no
1.b) Can The ARM-unit still move? yes/no
1.c) Are the wires/plugs connected correctly? yes/no

2. What is the condition of The ARM-unit when more problems occur?
Multiple answers are possible.

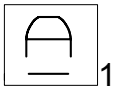
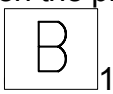
2.a) What mode is The ARM-unit in when the problems occur?

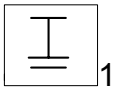
o  6 o  7 o  8

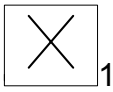
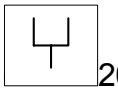
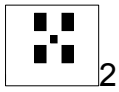
o  9 o  10 o  11

o  12 o no display o unknown

2.b) What does the system show when the problems occur?

o  13 o  14 o  15

o  16 o  17 o  18

o  19 o  20 o  21

o no display o unknown o complete malfunction

2.c) At which movements do the problems occur?

o left/right o up/down o drinking
o high/low control o wrist o gripper
o fold in o fold out o away from you
o towards you o unknown

2.d) What is the weight in the gripper when the problems occur?

o ±500 gram o ±1 kg o ±1,5 kg
o no loose object (for ex. a door) o none
o otherwise: ----------

2.e) In what position is the gripper situated when the problems occur?

o low (at the ground) o middle
o high (above the head)
o otherwise: ----------

2.f) Do the problems occur right after The ARM-unit is mounted on the wheelchair?yes/no

2.g) Are the accumulators well charged when the problems occur? yes/no

3. Do you have any further remarks?

7.3 Warranty terms Advanced Robot Manipulator

1. WARRANTY PERIOD:
Warranty on manufacturing errors of the specified equipment is applicable for an one year period.

2. CONDITIONS:
The user is responsible for:

2.1 Use of the equipment correctly in accordance with the operating instructions of Exact Dynamics.

2.2 Keep records of the equipment usage and performance and made them available to the Service Engineers of Exact Dynamics on request.

2.3 Not make any, alteration, addition or attachment to the equipment, except with the written consent of Exact Dynamics which shall not be unreasonably withheld.

2.4 The user will deliver or send the failing equipment, prepaid, in its original suitcase to the premises of Exact Dynamics.

3. RESPONSIBILITIES EXACT DYNAMICS:

3.1 Replace or repair components as necessary at no charge during the warranty period. Parts for which replacements have been supplied become the property of Exact Dynamics. Replacement parts are either new or equivalent to new, but will be in good working order.

3.2 Exact Dynamics will deliver or send the serviced or repaired equipment to the premises of the user, in a safe state and ready for use.

3.3 Exact Dynamics shall not be held responsible for:
(a) Any loss damage accident of injury caused by any defect, failure or breakdown of the specified equipment or part thereof.
(b) Any failure, defect or breakdown whatsoever caused directly or indirectly by the misuse of the specified equipment or any part thereof or by the operation thereof otherwise than by a duly authorised operator in accordance with the direction of the manufacturer or by negligence on the parts of any servant or agent of the user or by consequence of warlike operations, riot, civil commotion, fire, storm, tempest, inevitable accident or any cause event of circumstance beyond the control of Exact Dynamics.
(c) Any loss, damage or what so ever by transportation.

4. EXCLUSIONS

4.1 Warranty is contingent upon proper use of all equipment and does not cover equipment which has been modified without the approval of Exact Dynamics or which has been subjected to unusual physical or electrical stress.

4.2 Exact Dynamics shall be under no obligation to furnish warranty repair if adjustment, repair or parts replacement is required because of accident, neglect, misuse, failure of electrical power, air condition, humidity control, transportation, or causes other than ordinary use; if the equipment is maintained or repaired, or if attempts to repair or service
the equipment are made by other than Exact Dynamics or its agents without prior approval of Exact Dynamics. If warranty repair is required, in the opinion of Exact Dynamics as a result of causes stated above such repairs will be made by Exact Dynamics and a separate charge will be made.

4.3 Warranty also does not include operating supplies or accessories, plant or refinishing

the equipment, alterations for this purpose; electrical work external to the specified equipment, attachments or other devices not furnished by Exact Dynamics.

4.4 Exact Dynamics shall be relieved from the liability under this contract and to the extent that it shall be unable to carry out all or any of its obligations herein owing to wars, strikes, lockouts, governmental controls or restrictions where these or any other such causes are beyond all reasonable control of Exact Dynamics. However, the user advises of such situations arising.

5. ASSIGNMENT

5.1 The user may not assign or transfer warranty or any of its rights herein without prior written consent of Exact Dynamics.