TOUCH AND DESIGN

T’ND PROTOTYPE

Abstract

In this report we present the prototype of the T’nD system developed in WP6 – Development and Integration. The set-up of the system and its user manual are presented. This report is accompanied by a video showing how the prototype currently works. The video is available on the project web site.

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Author:	**M. Bordegoni**	Politecnico di Milano	WP leader
Approved By:	**U. Cugini**	**Politecnico di Milano**	**Project Coordinator**

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0. Index

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2. T’nD workstation

The T’nD workstation is made of several hardware and software modules.

Both the hardware and software modules include commercially available components and custom components that were developed as part of the T'nD research. Here follows an overall description of the T'nD workstation and the main modules it is made of; a more detailed description of the custom built hardware modules and the implemented algorithms is given in the following (Sections 5 and 6).

Figure 1 – T’nD workstation.

Figure 1 depicts the current configuration of the system. The visible components are two Haptic Masters (A, B) complete with their controller boxes (1, 2) and mounting hardware (3, 4), a suspended display (5) with its mounting rack (6) and a computer workstation (7). Currently, the Haptic Masters end-effector is the scraping tool (8). Other end effectors may become available in future.

2.1. The two Haptic Masters

Current configuration of the system is based on two Haptic Masters (A, B) as each device provides 3 active degrees of freedom (DOF) while the T'nD application requires more. This has already been discussed in detail in [1]. The configuration of the system may change before the end of the project if different devices will become available.

Each Haptic Master (HM in the following) can be classified as a 3 DOF, active, bidirectional, general purpose haptic device according to the classification suggested in [2, 3]. Its peculiarities include a wide workspace combined with a high position resolution (usually, the wider the workspace, the lower the resolution), the ability to exert forces up to about 200 N and the end-effector force sensor that is used in the control loop as explained in the following section.

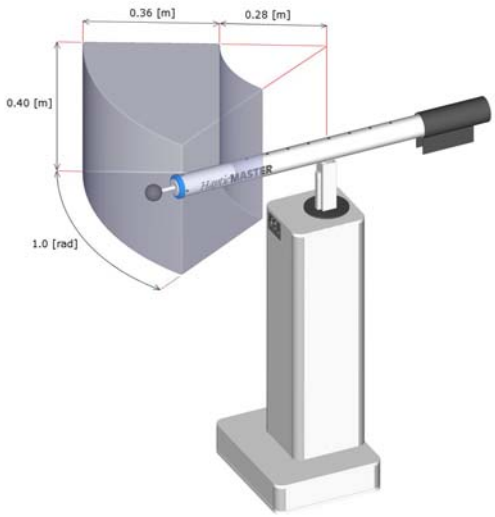


Figure 2 – HapticMaster workspace.

More precisely, the workspace of a single HM is shaped as in (Figure 2). It has a total volume of 80 [litres]. The position resolution is between 4 an 12 [µm], thus resulting in a workspace volume of about 710 * 10^{12} voxels. The maximum attainable stiffness of rendered virtual objects ranges from 1 [N/mm] in the sideways direction to 40 [N/mm] in depth, measured at a force of 10 [N].

2.1.1. The controller boxes

Each HM is driven by a controller box that actually contains a dedicated personal computer implementing the haptic control loop and various local primitives (forces, masses, springs, dampers and basic geometric shapes with associated properties). The operating system run is the VxWorks real time O.S. The innermost lower level control loop runs at 20 KHz, and the modelling loop runs on a hardware interrupt at 2500 [Hz]. The control loop has the peculiarity of being based on a force sensor placed at the device end-effector, allowing a closed loop control where the actual exerted force is measured and compared with the requested force. The term used by FCS to indicate this kind of control is "admittance controlled", as opposed to "impedance controlled", where the forces are pre-determined based on motors characteristics and device kinematics, like in most of other commercially available haptic devices.
In impedance control, the paradigm is the following: the user moves the device, and the device will react with a force if needed. This is the basic interaction between the user and the control loop. Viewed from the control loop, the paradigm is the following: "displacement in - force out".

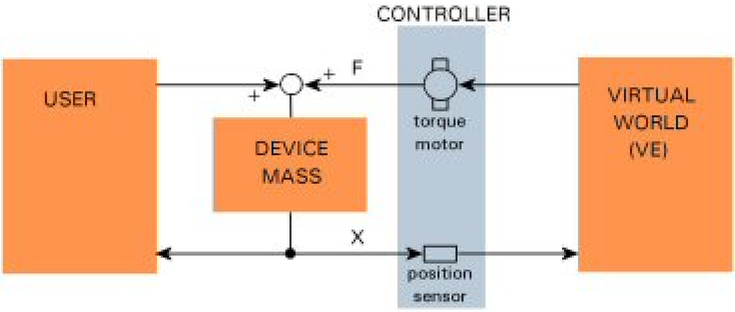


Figure 3 – Impedance control paradigm

In simulated free air, the user is free to move the device, and the motor does not have to do anything. In control terms: the gain from changes in position to changes in motor force is zero. This will hold even if the device is in contact with a hard physical surface. There is no special stability problem there, since the object can stop the end-effector without any special reaction being required of the motor.

In contact with a simulated hard surface however, there is a stability problem. Any small change in position will cause a very high rise in motor reaction force while the device is in contact with the virtual wall. This implies a very high control gain from measured device position to motor force. For stability, control gains cannot become infinitely high. Therefore, in an impedance controller there is a limit to the "hardness" or stiffness of a virtual surface that can be rendered stably.

In admittance control, the paradigm is the following: the device measures the forces that the user exerts on it, and reacts with motion (acceleration, velocity, position). Viewed from the control loop, the paradigm is the following: "force in - displacement out".

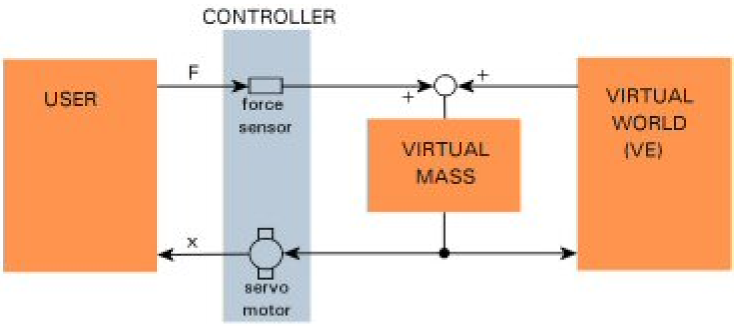


Figure 4 – Admittance control paradigm.

In order to simulate free air, the device needs to accelerate very quickly at the lightest touch. This means a very high control gain from force input to acceleration output. A very low simulated mass means a very high control gain. So, admittance controlled devices have a potential stability problem in free air, when the mass needs to be low. The same holds on a physical hard surface. A small movement of the machine will give a strong rise in contact force from the physical surface. It is the physical environment which closes the admittance control loop with a very high gain from position to force this time, creating contact instability. On a simulated virtual surface however, a very high force will command only a very small motion. In fact, on for an infinitely stiff simulated surface, the control gain from force to position is zero.

Admittance control and impedance control are then dual. What is difficult for the one is easy for the other, and vice versa, as shown in the following table:

	Impedance	Admittance
Low mass	+	
Stable on physical surface	+	
Low costs	+	
Low friction		+
Stable on virtual surface		+
Can simulate added mass		+
Crisp master-slave control		+
Robust device		+

Admittance control is the paradigm of choice in the following cases:

- simulated contact with stiff objects.
- simulated contact with heavy objects.
- total elimination of friction.
- robust devices (stiff, strong or large machines, large workspaces).
- moving larger physical masses.
- detailed measurement of forces.

Impedance control comes into its own in the following cases :

- safe, light and passive movements.
- contacts with hard physical surfaces.
- very low simulated mass, but with some friction allowed.
- small, low-cost devices.

2.1.2. The mounting base

The mounting base (3) and the stiffening bracket (4) were custom built in order to satisfy the following requirements and issues:

- In order to compute the geometrical transformations discussed in [1] it is necessary that the relative positions of the two HMs are fixed and known in advance.
- The forces exerted by an HM are enough to make it tilt, requiring it to be fixed to an appropriately solid and heavy basement.
- The HM devices may experience stability problems. This is normally solved by an appropriate tuning of the "driver" (controller box software) parameters, but in this specific system there are two HMs linked to the same end-effector which tends to amplify the stability problems and to make parameters tuning more difficult. In order to reduce the stability problems it helps to change the resonance frequencies of the system by increasing the rigidity of the assembly.

The mounting base is a block of mild steel that measures 900 x 500 x 10 mm and weights about 46 Kg, nevertheless the forces exerted by the HMs were still able to flex it when combined with the resonance effect. The stiffening bracket was added later and helped to reduce the phenomena and to make the whole system more stable.

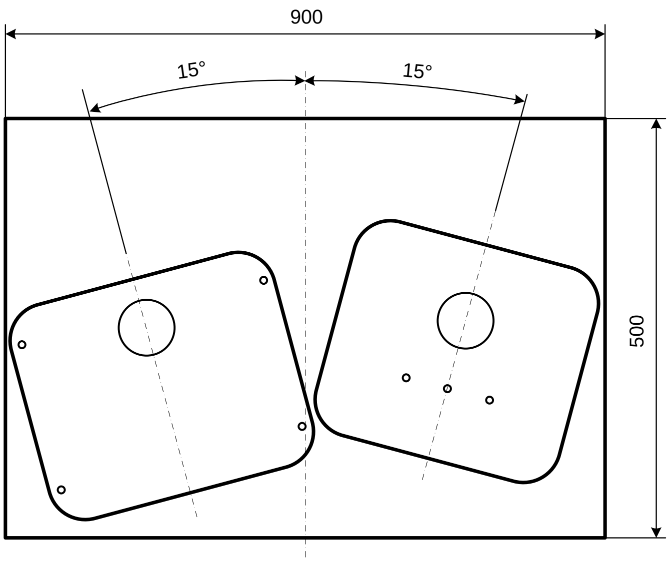


Figure 5 – Drawing of the mounting base.

The base was built, and the HMs were positioned on it, as specified in the drawing (Figure 5). The reason the HMs bases look like they are positioned asymmetrically is that the two HMs used in the TnD project are not equal. They were built in different years with different specifications and they have a different positioning of the axes, different arm travels and consequently a different workspace. The positioning of the HMs was done so that the centers of their respective workspace were about symmetrical, and the medial vertical planes made and angle of 15 degrees each, to the medial vertical plane of the system. The angle is 15 degrees as suggested by FCS-CS in order to maximize the common workspace, to keep both HMs work in favorable conditions and to reduce stability problems.

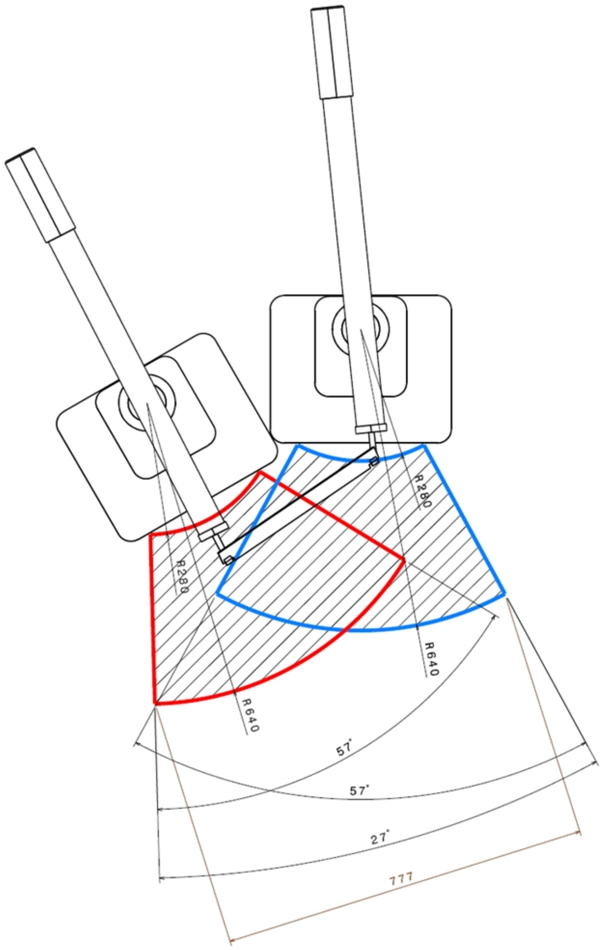


Figure 6 – Common working space.

The resulting common workspace is reported in (Figure 6) in which also the most important dimensions are depicted.

2.2. The display

The display is currently a commercial 20" LCD display.

In order to increase the realism of the virtual scene, it is suspended just above the HMs workspace so that the user is operating with his hands under it. The idea behind this is that the whole system purpose is to let the user operate like he would do in reality. This includes the fact that he should look in the same direction as he would when modeling clay in real life, that is, looking towards his hands and scraping the model with the tool. So the display is placed as closed to the hands as possible, and the scene is represented with perspective parameters that mimic the actual point of view of the user related to the model position.

The mounting rack has an articulated arm capable to keep the display in place and allow some adjustment to different users' height and taste. Currently, the mounting rack also serves to delimit the working space of the system thus making the operating environment safer.

2.3. The computer workstation

The computer workstation is a 2.8 GHz IBM personal computer running Windows operating system. The main T'nD application, that is, the modified think3 system described both in previous deliverables [1] and in the following sections (§ 6 and 7) runs on this machine and controls the

HMs via network. Actually, there are no special requirements for the workstation as the T’nD application can run on any networked machine where think3 does, but it is advisable it is located close to the system as running the application requires human interaction with the HMs.

In addition, the workstation has a dual monitor setup that allows us to control the display described in previous paragraph with no need for special hardware/software setup for duplicating the image elsewhere.

2.4. The end effectors

There are currently two end-effectors (“tools”) being developed: the scraping tool, already functioning, used to simulate clay modeling by means of a rake and the sanding tool, still on development and going to be patented, used to simulate both sandpaper finishing and manual exploration of the produced model.

3. User Manual

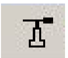
The T’nD system is a customization of the think3 CAS/CAD application. Its interface is based on thinkdesign user interface. T’nD specific functions are available through dedicated “Touch and Design” toolbar. If not present by default, the toolbar can be added by right clicking on the grey area and selecting the “Touch and Design” menu item.

The following picture shows the buttons available in the Touch and Design toolbar:

The buttons are named, from left to right:

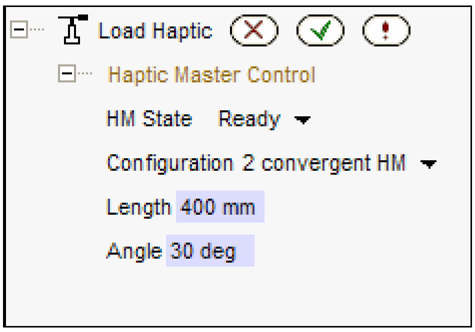
- Load Haptic Device
- Tool Configuration
- Explore
- Scraping
- Unload Haptic Device

and will be described in more detail in the following. The sixth button is not properly a T’nD functionality, but activates an emulation modality used by developers when they need to test the system without having the HapticMasters physically connected.



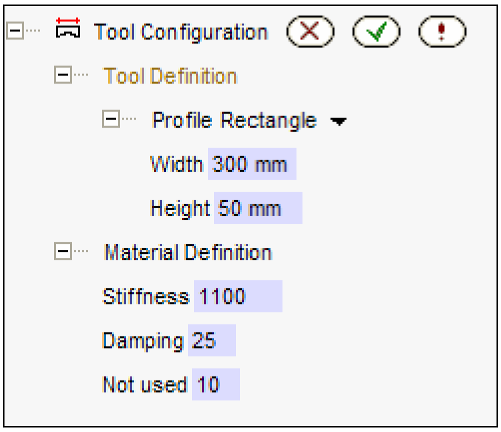
Load Haptic device

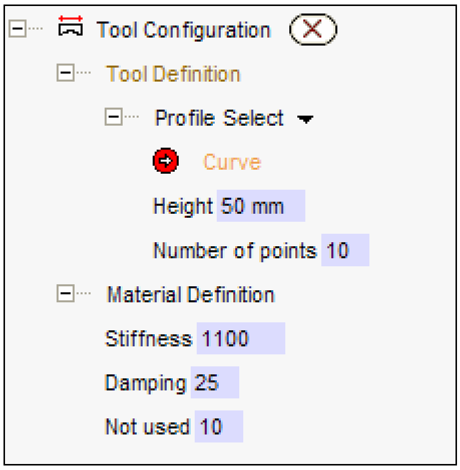
Once the haptic devices are powered, it is possible to initialize them with the command load haptic device. The first time this command is invoked after power on, it causes the execution of the self-calibration procedure of the HMs. The devices must not be touched during this procedure; ignoring this caution will result in mis-calibration of the devices and consequent mis-funcioning of the system. Subsequent invocations of this command will not cause the self-calibration procedure to be re-executed unless one or both the devices were cycled through power off / power on after the last invocation.
The dialogue box associated to this command includes options allowing to choose between different configurations (different layouts of the system) as well as to set the geometric parameters of a specific configuration, like the axes distance or the angle between the devices.

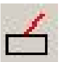


Tool configuration

This command permits to the user to define the layout of the virtual rake that will be used. The default tool is a rectangle having predefined dimensions. The parameters that can be changed are the width and height of the rectangle; furthermore, the lower edge of the rectangle can be substituted with an arbitrary curve, thus allowing for easy generation of complex shapes. The user can choose the number of adjacent segments that approximate this curve as well.

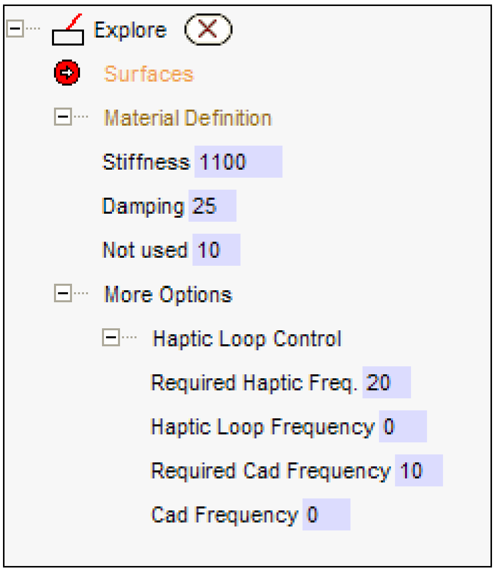






Explore

The explore command allows the user to touch the model without modifying it. It can be applied at any stage of modeling, i.e. to explore the initial clay block as well as the intermediate models produced or the final product. The tool used in this exploration is the rake used also in the scraping operations and can be setup using the "Tool configuration" command.
The user can also set the material stiffness to different values according to the nature of the simulated material or just to his own preferences. The possible stiffness values are limited in the range 500 N/m to 10000 N/m, 500 corresponding to a "very soft" material (nearly grease) and 10000 being the limit at which the devices start to show stability issues.



Scraping

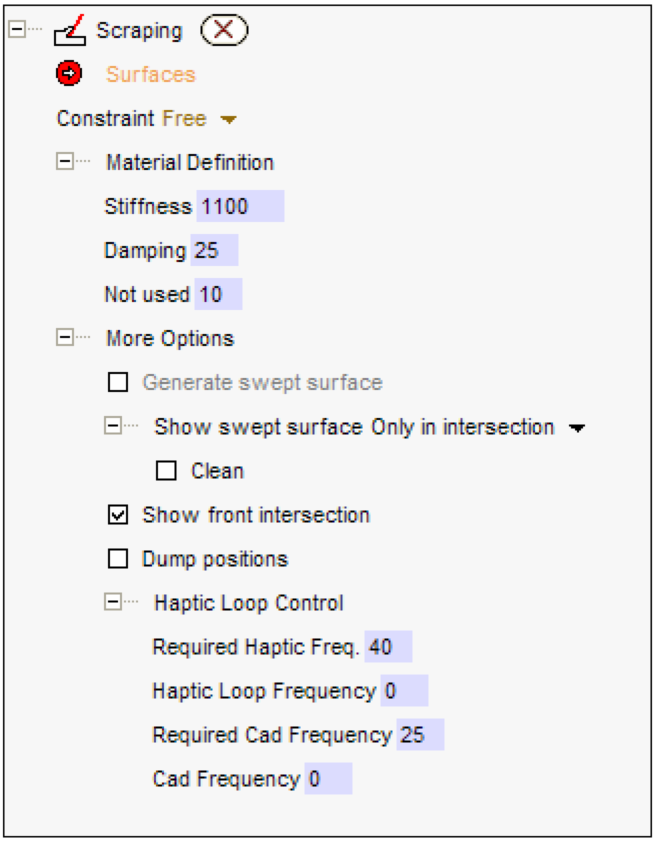
The scraping command allows the user to model the clay block by means of the scraping tool (the "virtual rake" optionally set up via the tool configuration button above). On each "pass" the user pulls (or pushes) the tool over the clay block at an arbitrary depth, like he would do in real life. The begin and the end of a pass are automatically detected depending on how long the tool is "in" or "out" the clay block (about 500 ms in current implementation). After each pass is ended, the material is automatically removed from the model, the graphic visualization is updated and another pass can be performed.

The material stiffness (like in the explore command), but also the cutting force associated to the material, can be set.

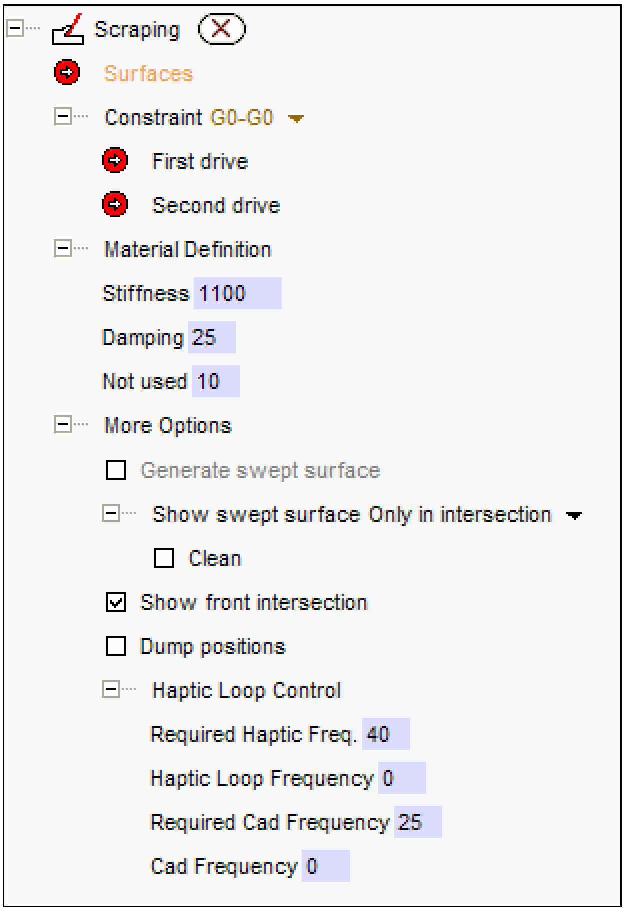
Also, a constrained motion modeling modality is available from this command. In this modality, the tool can not violate one or more arbitrary geometric constraints thus forcing the creation of a model that is guaranteed to satisfy certain properties. The available constrained are called G0 (the tool can not surpass an arbitrary curve), G0 + G0 (two arbitrary curves) and G1 (motion is constrained by tangency of the lower edge of the tool to an arbitrary surface). While these modalities are active a force tends to guide the tool to respect the constraint. This force is weak when far from the constraint and increases in intensity while approaching it.

- Scraping (free or under constrained motion):
  a. In Free mode, this is similar to the Explore command, but in addition the scraping produces a swept surface. The scraping is automatically recorded from the first collision until the last one or if the user stops to move the tool or goes backwards.

  The visualization of the swept surface, the tool and/or the intersection can be disabled.



b. In Under constrained motion mode, the user can as well select optionally 1 or 2 drives (contours of curves), one of them being possibly a curve on surface. In this case there is no surface generation until the tool do not collide any drive. As soon as the user is close to the drive the tool is "snapped" onto the drive and the motion is constrained along this drive until there is no more collision.



Unload haptic

This command allows the user to block the haptic devices in a defined position for temporary stopping the modeling operations or for safety issues. This is necessary because when the HM devices are in their normal operating mode, they can't be left unattended. There must always be an operator properly holding their end effectors (the tool) that is, taking care they don't touch each other. Failing this caution could result in damage to the devices and/or the operator. The operator can stop holding the tool only after this command is invoked.

Safety Issues

Due to the relevant forces that HMs can exert a few important safety rules must be respected. They are summarized in the following few issues:

1. Always consider the working space of HMs as a non-safe area: take care when operating inside it.
2. Both HMs are provided with two emergency inter-blocking pushbuttons. Be sure to be always in condition to operate promptly to these buttons in case of necessity.
3. Do not touch HMs during initialization phase. Inappropriate calibration leads to unpredictable reactions and forces.
4. Do not move the tool in unconventional fashions being careful to avoid collisions between the two HMs.
5. Do not abandon the tool without any control. Always block the HMs with the proper command before leaving them unchecked.