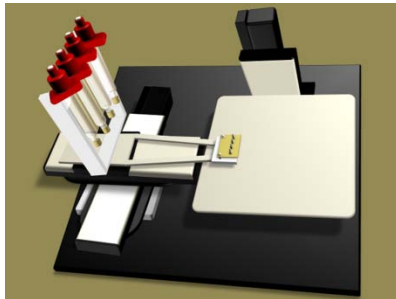


[DRAFT] NOT FOR DISTRIBUTION



TissueWorks[®] Command Center

Software User Manual

[DRAFT]

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Brigham and Women's Hospital
Harvard Medical School

Tissue Imaging / Engineering Laboratory 

Warnings and Important Check List

- Do not touch or apply force to the printer while the robot is moving.
- Before starting the printing sequence, make sure the operating condition of air pressure tank, valve, dispenser, tubings, and valve controller. Also check the all appropriate fluid lines and tubings in functional order.
- Before starting the software, make sure to turn the power of robot controller (Newmark System). The robot stages will not work properly if power supply is off.
- Do not turn off the robot controller while the robot stage is in action. Premature removal of power can result in damage to both controller unit and robotic components

Make sure to clean the dispensers before and after each use. Clogs are the primary cause for premature failure of the dispensing unit.

About the Icons



Icon for warning and items that need attention



Icon for marking important notes



Icon for useful information.

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Credits

Dr. Jong-Hwan Lee wrote the TissueWorks-Nexus (TW-Nexus), and Vivian K. Lee and Wonhye Lee composed the TissueWorks-Command Center (TW-CC). We acknowledge the efforts from Karl Edminster in the hardware design. Contributions from Philip Keegan, Jason Pinckney, Jason Debasitis, Francis Doyle, Samuel Polio, and Dr.Yeong-Bae Lee during the beta testing and upgrade of the system are gratefully acknowledged.

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Introduction

TissueWorks–Command Center (TW-CC) is the user-interface for control of the printing actions for the 3D Bio-Printer (3D BP). The design of the interface allows the user to easily input custom patterns and spatial concentrations for the generation of unique cell-matrix composites.



TissueWorks–Nexus (TW-Nexus) is MATLAB-based software environment utilized to create user-defined printing pattern, to adjust the printing resolution, and to visualize the 3D printing morphology. The TW-Nexus will create .crd files for the TW-CC for printing.

TW-CC was developed using Visual Basic .NET platform and ActiveX Toolkit by the Galil Motion Control, Inc., and will work under the Windows XP. In order to enable the installation of the software, you need to download .NET Frame Work 2.0 (freeware) and ActiveX Toolkit by Galil Motion Control, Inc (<http://www.galilmc.com/>).

Minimum hardware requirement is Pentium II 400MHz and 128MB RAM.

Recommended hardware requirement Pentium III 400MHz, 256MB RAM.

Recommended OS is Windows XP and above.

Currently, Windows VISTA is not supported. Upon the arrival of VISTA compatible ActiveX Toolkit (depending on the Galil Motion Control, Inc), we anticipate that the software will be VISTA-compatible.

Components of 3D Bio-Printer



Tissue Works Nexus Command Center

Controls the 3D
Tissue Printer and
Printing
procedures



Robot Controller

Interfaces
The software and
the 3D Tissue
Printer



4Ch Valve Controller

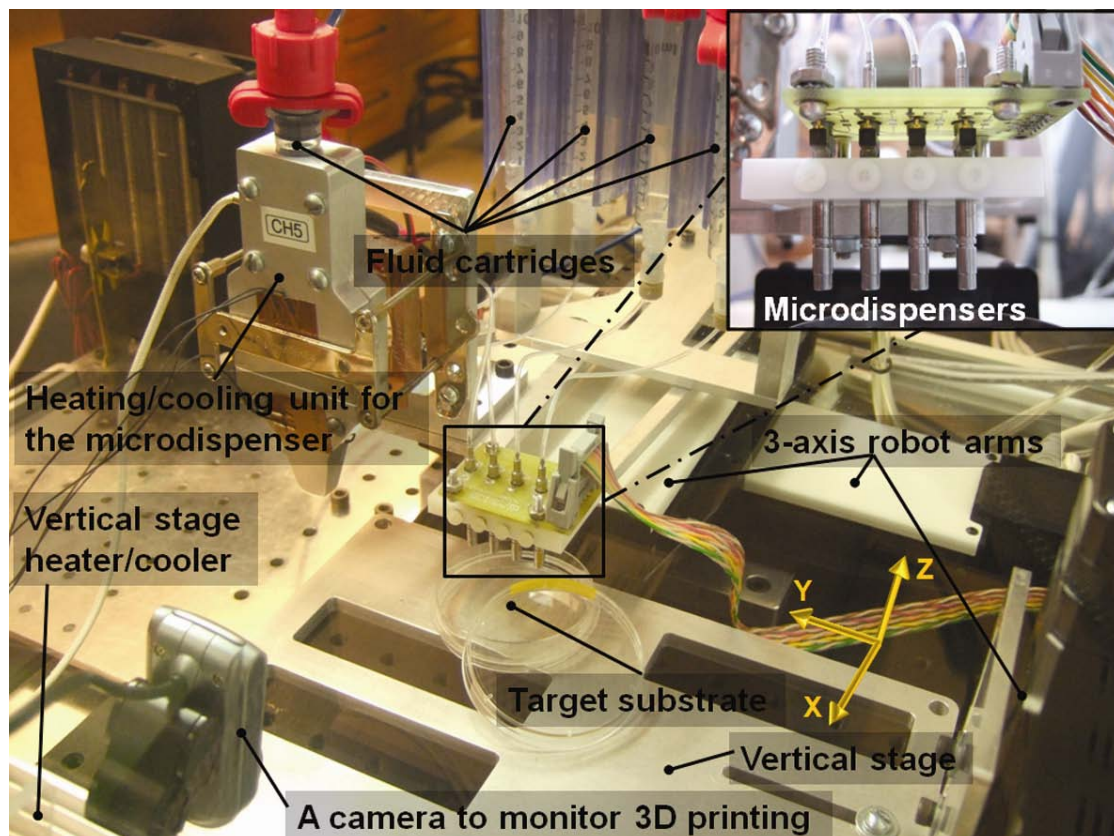
Adjust the droplet
size and
dispensing speed

Connected with Air tank and
Pressure Regulators



Robot (3D Cell Printer)

Place where the
cell printing
occurs



Installation

■ Galil Motion Control, Inc. ActiveX Toolkit

1. Execute the file 'dmcocx02.exe' from the CD-ROM included in the 3D BP.

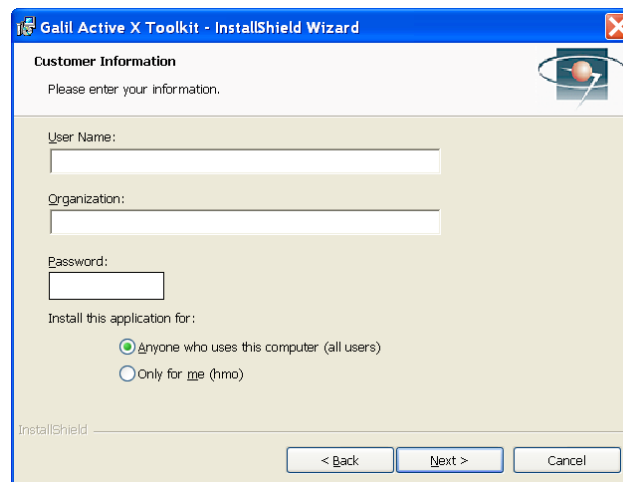


You can also download the file directly from <http://www.galilmc.com>
(<http://66.60.181.132/xnet/checkreg.aspx?location=software&target=dmcocx02>)

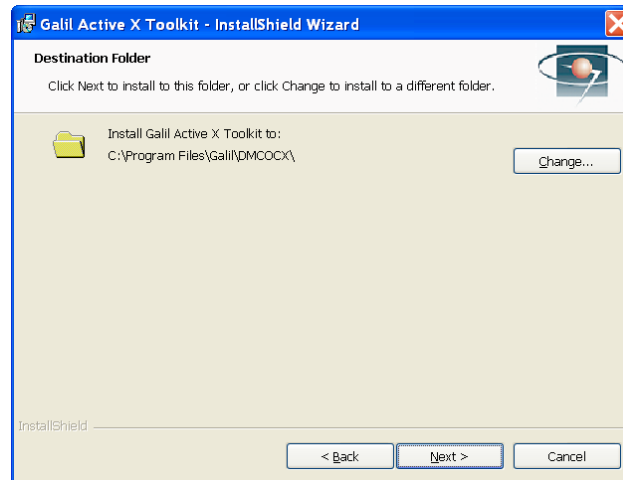
2. From the window below, click 'next' to continue the installation.



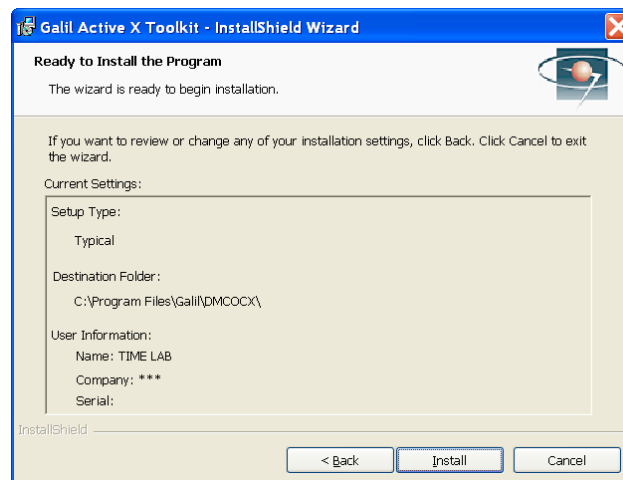
3. Enter username, organization, and password (will not be available for public use). Click 'next' to continue the installation.



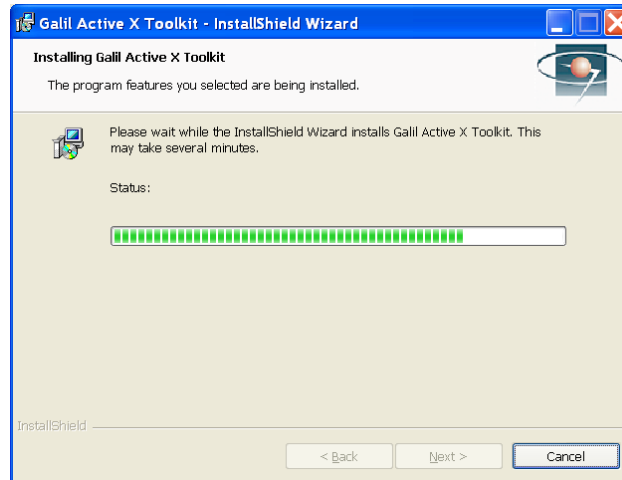
4. Based on the window below, define the installation pathway, and click 'next' to continue the installation.



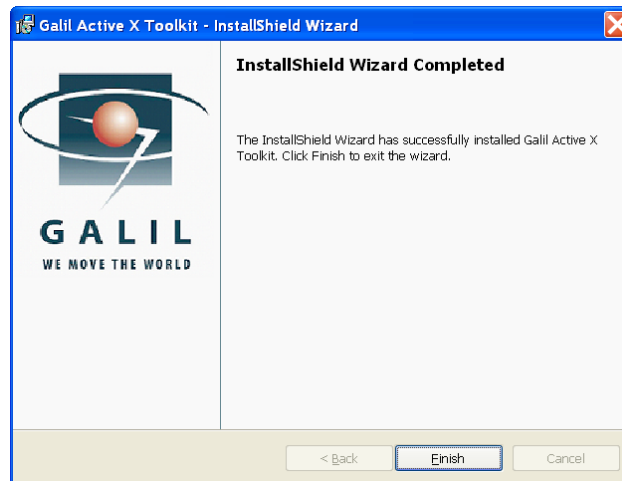
5. After confirming the installation parameter, click 'install' to start the installation.



6. The next window indicates the process of installation.



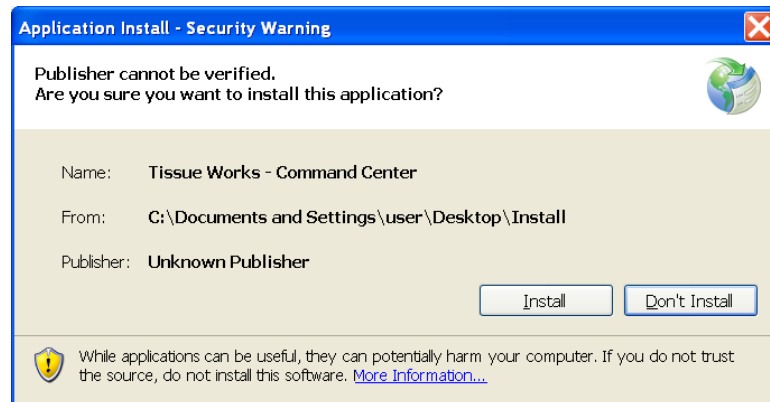
7. After the successful installation, the window below will pop up. Click 'Finish' to complete the installation.



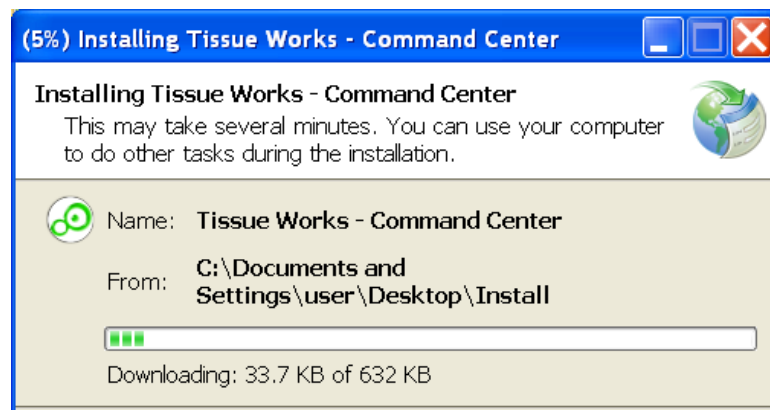
You have to install the ActiveX Toolkit to operate/use TW-CC. Please install ActiveX Toolkit prior to use.

■ TissueWorks–Command Center (TW-CC)

1. Execute the file 'Setup.exe' from the CD-ROM included in the 3D Bio-Printer.
2. From the window below, click 'Install' to continue the installation.



3. The window below indicates the installation process



4. After the installation, go to 'Start' → 'All program' → 'Time Lab' – "Tissue Works – Command Center" to start the program.



If .NET Framework 2.0 is not installed, the installation button for the .NET Framework 2.0 will appear. In this case, install the .NET Framework 2.0 prior to the software installation.

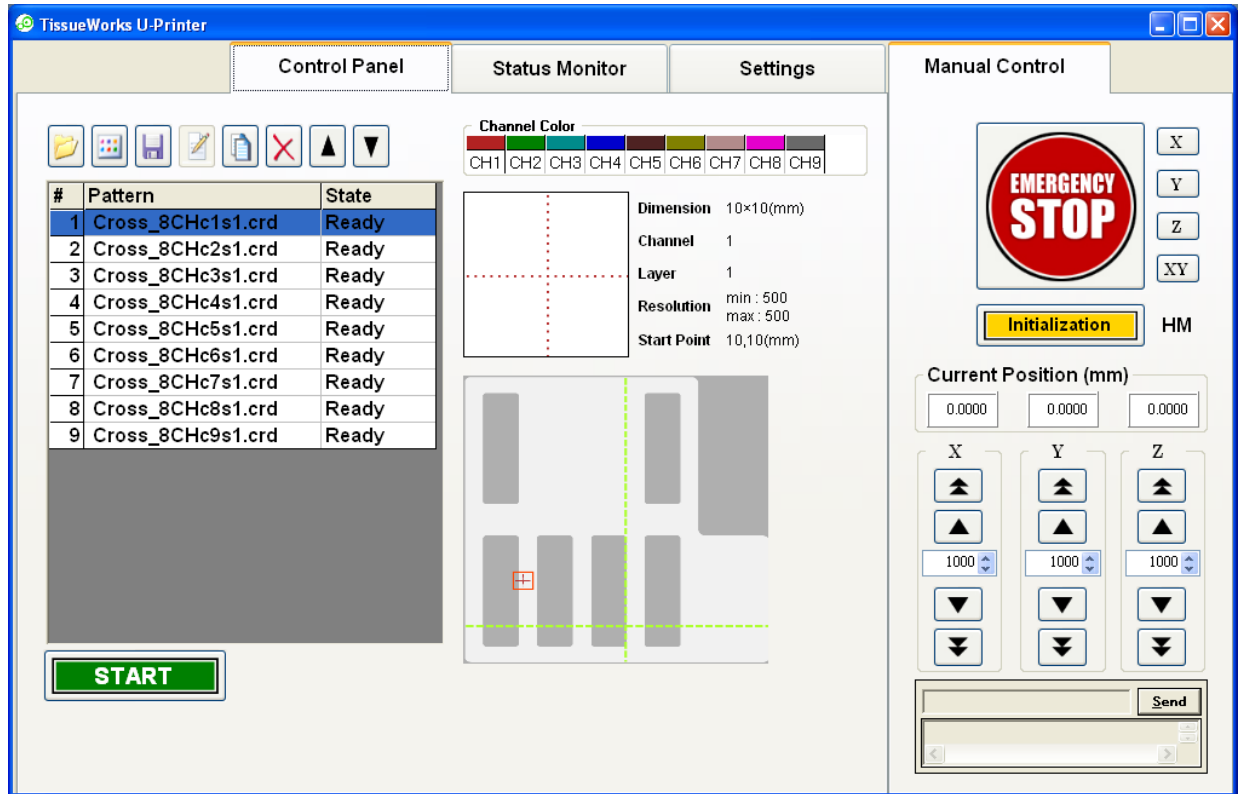
How to Start/Stop the 3D Bio-Printer

1. First, check the surroundings around the printer. Make sure there are no objects that block the movement of the stage. Check to make sure that all the connections are correct and the power is appropriately supplied to the printer.
2. Turn on the power switch to the robot controller (newmark systems, inc) and microvalve controller (electromechanic, inc.).
3. Start the TW-CC.
4. After the 20~30 seconds of initialization, Make sure that 'Current Position' indicates the 0's in all x y and z coordinates. If not, please push the **INITIALIZATION** button to initiate the printing procedure.
5. After the printing, close the TW-CC window to end the program.
6. After ending the TW-CC, turn off the robot controller (newmark systems, inc) and microvalve controller (electromechanics, inc).



Make sure that you turn off the power to the robot controller AFTER the quitting the software. Otherwise, the TW-CC may encounter software errors due to problems of software-hardware communication.

Interface

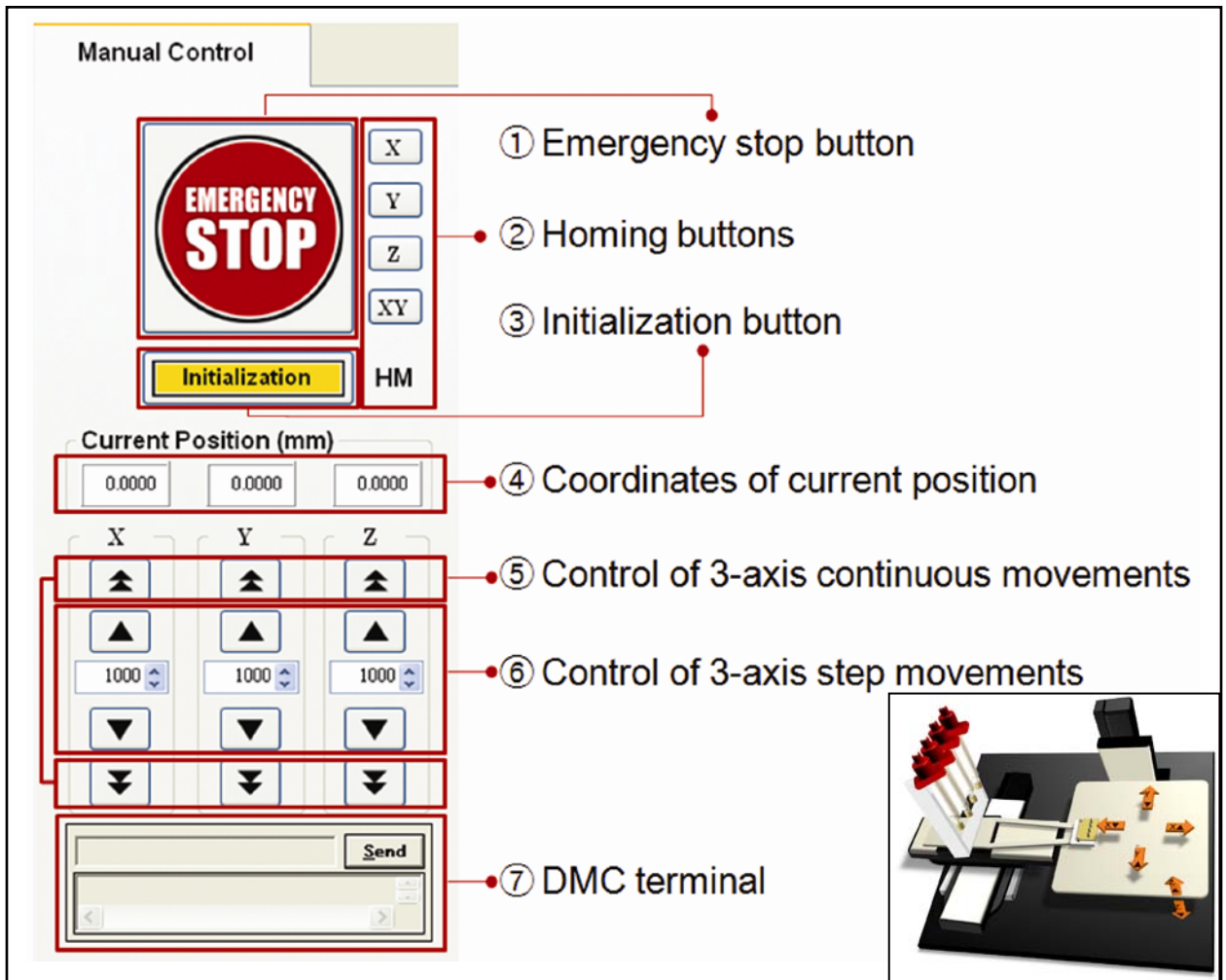


TW-CC consists of four tabs as shown in the above. The *Control Panel* tab is used for the preparation of the robot stages, as well as processing the printing protocols. During the execution of printing action, the screen automatically switches from the *Control Panel* window to the *Status Monitor* window. The *Settings Panel* is utilized to adjust the setting of dispenser coordinates, origin, softlimit, and etc. The *Manual Control* tab, is independent from the above three tabs, and allows for manual adjustment the 3-axis robot.

■ Manual Control

Manual Control allows for monitoring the x-y-z coordinates of 3-axis robot, and enables manual movements of robotic arms.

□ Components of the Manual Control



① Emergency stop button: Clicking this button immediately stops all the robot motions.



This button is designed to stop the robot motion in emergency, but there might be a time delay due to the communication time between TW-CC and newmark robot controller. In order to cease the robot printer instantly, turn off the power of newmark robot controller. In that case, you need to restart TW-CC after turning on the controller.

② Homing buttons: These buttons move the designated robot arm(s) to its coordinate defined as its home. The home locations are concerned with the hardware limits of movable ranges of robot arms.

③ Initialization button: This button first moves 3-axis robot arms to each home coordinates (hardware limits of movable range), and then moves the arms to user defined origin. After the completion of robot motions, TW-CC defines the final location as (0, 0, 0). of (x,y,z) coordinates. The initialization is automatically executed with the startup of TW-CC. If it is not, then you need to execute initialization manually using this button. This process is completed within one minute.

⚠ The initialization process uses hardware limits of robot arm moving range (home locations), and the user-defined origin is defined concerned with the home locations. During our beta testing, sometimes re-initialization changed the origin locations from previously defined origin up to several hundred micrometers. To prevent this problem, do not use this initialization button during processing a printing sequence.

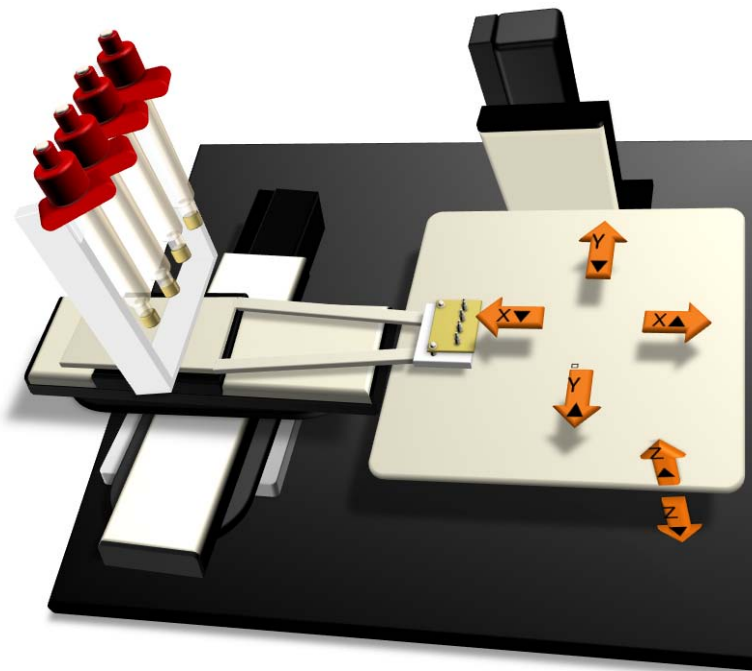
④ Coordinates of current position: Relative x-y-z coordinates to user-defined origin (0, 0, 0) are shown on these boxes. These coordinates are in mm and the information is updated in every 0.1 second. Depends on status of communication between TW-CC and newmark controller, there might be a delay for updating coordinates.

⑤ Control of 3-axis continuous movements: These buttons move the robot arms continuously while the button is pressed down. The motion will stop when it is released.

⑥ Control of 3-axis step movements: These buttons move the robot arms a step of user-defined travel distance in μm per each click. The step of travel distance can be defined in the range of $1\ \mu\text{m}$ and $10000\ \mu\text{m}$.



The following illustrates the direction of movement of the robot stage in different axis.



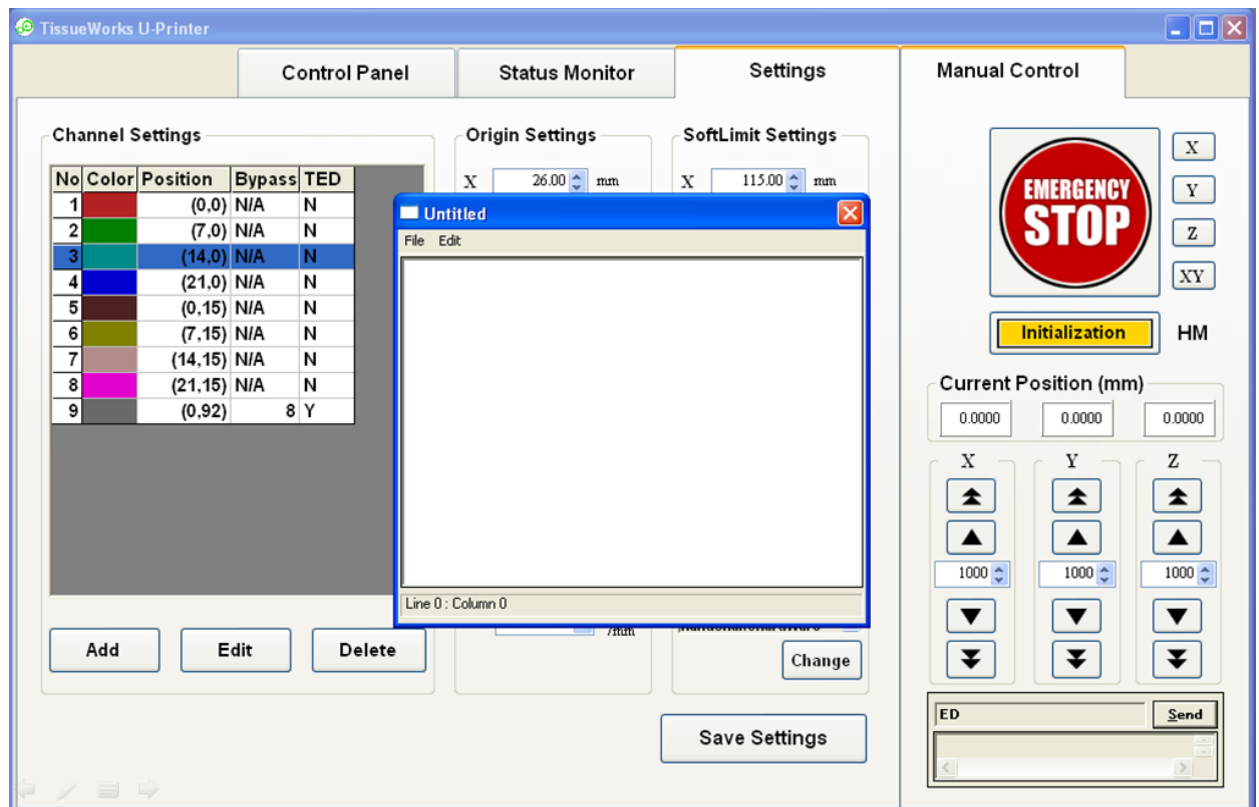


If the movement (both continuous or step) passes the soft limit, the robot movement will be automatically stopped. Soft limit will restrict the movement range for safety reasons. Please refer to the p/xx SoftLimit section.

⑦ DMC terminal: Script-based command offered by Galil Motion Control, Inc., can be entered and executed. The response from the robot will also be displayed in the same window. More information on the commands can be found from the Galil Motion Control, Inc. (www.galilmc.com) DMC-2xxx Series Command Reference



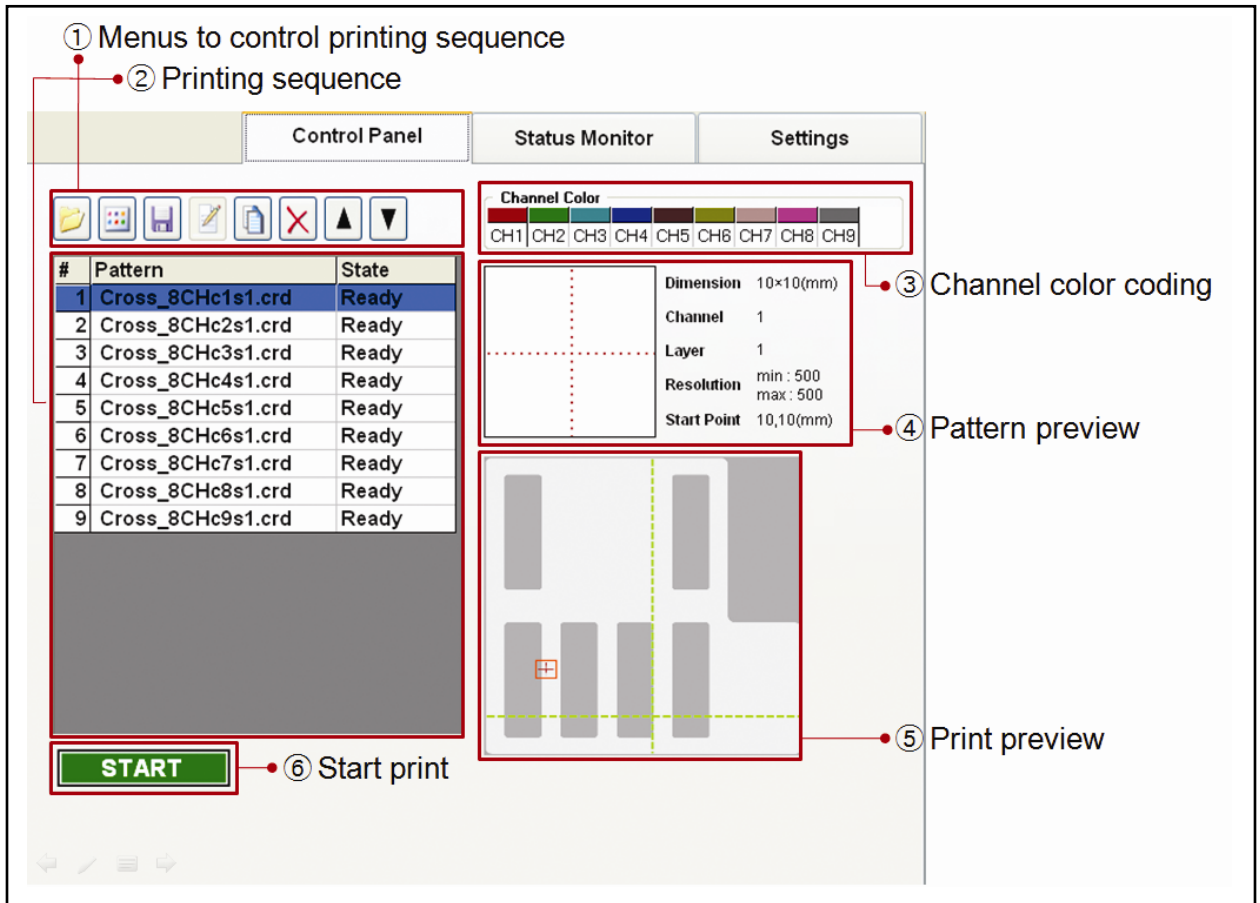
In DMC terminal, enter 'ED' to evoke the text editor for the robot command. This window can allow the mathematical algorithms and programming logic that cannot be entered directly to the command window.



■ Control Panel

The Control Panel allows the management of a printing sequence, and pattern preview with detailed information and print preview of each pattern in the printing sequence.

□ Content of the Control Panel



① Menu to control printing sequence



Load external patterns (.crd files) or previously saved printing sequence (.lst files)



You can select multiple files.



Add pre-designed internal patterns



See p/xx for more detailed contents and types of patterns



External files (.crd files) are used to import printing patterns with complex shapes and sizes. Internal patterns are used for simple square or concentric patterns.



Save current printing sequence as a list file (.lst)



Edit the selected internal pattern.



Copy the selected internal/external pattern and add it to the end of current printing sequence.



Delete the selected pattern from current printing sequence



Move the selected pattern up to promote the printing order.



Move the selected pattern down to demote the printing order.

② Printing sequence: Current printing sequence is shown, which can include both internal and external printing patterns at the same time. The order of the sequence can be adjusted. The status of each pattern can be labeled as follow; Ready, Running, Pause, Stop, and Complete.

③ Channel color coding: The channels are color-coded. The printing pattern can be previewed according to this color scheme.

④ Pattern preview: The pattern preview with detailed information of the selected pattern in printing sequence appears in the pattern preview window. The image of the pattern is resized to fit the square box and shown as a preview. The detailed information of the pattern includes dimension of the pattern, designated channel and layer, and spatial resolution and start point of the pattern.



The layer of internal pattern is defined as '0'.

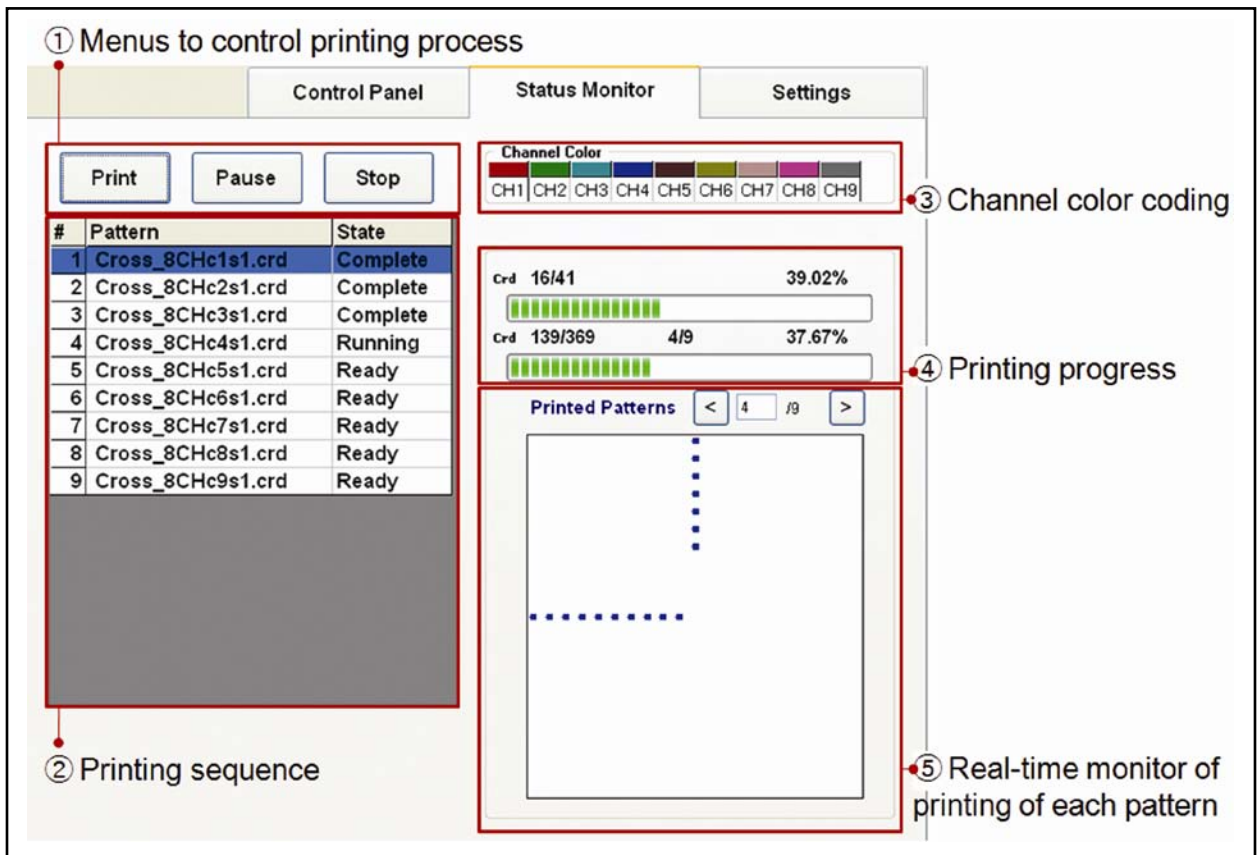
⑤ Print preview: Shows the relative size and location of the selected pattern with respect to the vertical stage.

⑥ Start print: By clicking the 'START' button, the printing sequence starts to be printed; Panel of TW-CC is automatically changed from control panel to status monitor automatically.

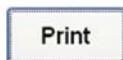
■ Status Monitor

Status Monitor panel allows the control of start, pause, and stop of the current printing process and shows the progress and real-time monitoring of printing.

□ Components of Status Monitor



① Menus to control printing process



Starts the printing action from pattern with status of pause or ready



Pause the printing action and label the state of on-printing pattern as pause.



Stops the printing process of the printing sequence. After printing has been stopped, next printing of the printing sequence will start from the first pattern.

② Printing sequence: Current printing sequence is shown, which can include both internal and external printing patterns at the same time. The order of the sequence can

be adjusted. The status of each pattern can be labeled as follow; Ready, Running, Pause, Stop, and Complete.

③ Channel color coding: The channels are color-coded. The real-time printing of each pattern can be shown in real-time monitoring box according to this color scheme.

④ Printing progress: Upper progress bar shows the progress of printing of current pattern, and lower progress bar shows the progress of printing of printing sequence. The two bars show the progress of given printing sequence as well as the completion of overall printing task

⑤ Real-time monitor of printing of each pattern: Each printed dot is shown in real-time monitor as printing occurs pattern by pattern. Printed patterns can be reviewed in using the pattern selection buttons (<, >).

■ Settings




Settings panel allows the control of the settings for 3D bio-printer.

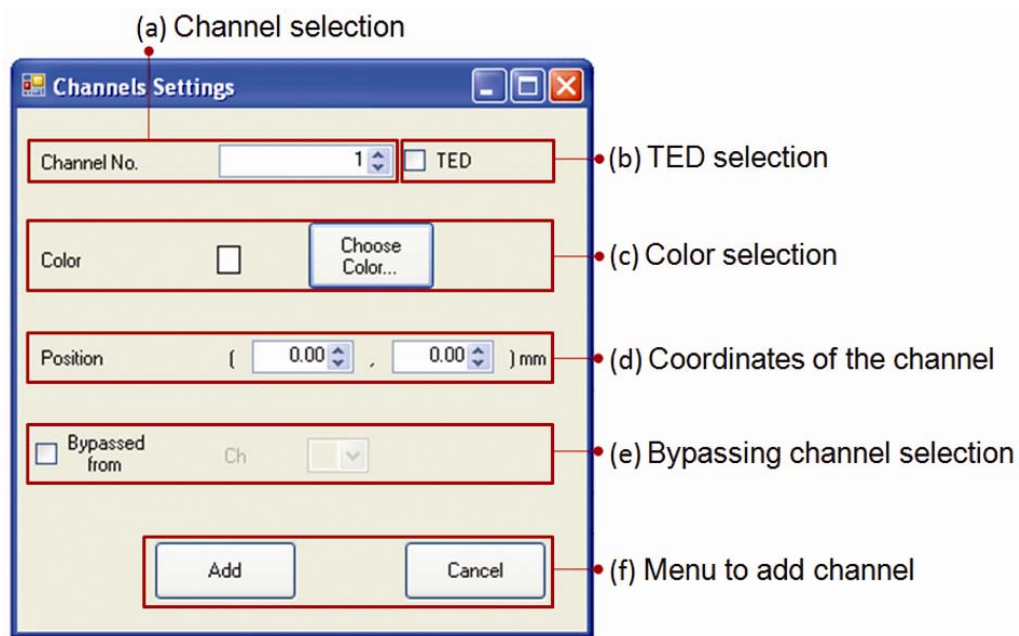
□ Components of Settings

The screenshot shows the 'Settings' tab of a 3D bio-printer interface. It contains several sub-panels: 'Channel Settings' (a table with 9 rows), 'Origin Settings' (X, Y, Z coordinates), 'SoftLimit Settings' (X, Y, Z limits), 'Speed Settings' (robot speed), 'Motor Settings' (steps/mm for X, Y, Z), and 'Controller Settings' (controller type and revision). A 'Save Settings' button is at the bottom right. Numbered callouts point to specific features: 1. Channel Settings table, 2. Add/Edit/Delete buttons, 3. Origin Settings, 4. SoftLimit Settings, 5. Speed Settings, 6. Controller Settings, 7. Save Settings button, and 8. Save Settings button.

No	Color	Position	Bypass	TED
1	Red	(0,0)	N/A	N
2	Green	(7,0)	N/A	N
3	Blue	(14,0)	N/A	N
4	Dark Blue	(21,0)	N/A	N
5	Brown	(0,15)	N/A	N
6	Olive	(7,15)	N/A	N
7	Pink	(14,15)	N/A	N
8	Purple	(21,15)	N/A	N
9	Grey	(0,92)	8	Y

① Setting of channels: Setting values of designated number of dispensers, relative coordinate to user-defined origin coordinate of each dispenser, bypass source channel, and TED integration application (theremoelectric device) are shown.

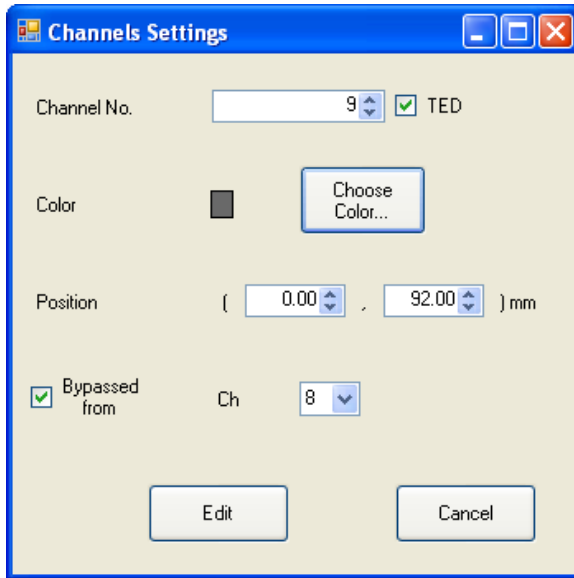
② Menu to set channels: Channel(s) can be added, edited, or deleted using , , and , respectively.



- (a) Channel selection: Channel number needs to be designated.
- (b) TED selection: For the channel with thermoelectric device (TED), this option needs to be selected.
- (c) Color selection: Color for the channel can be defined.
- (d) Coordinates of the channel: (x, y) coordinates of the channel must be set. This coordinates are relative positions between dispensers. The channel with origin coordinates of (0, 0) can be any channel, but relative coordinates of other dispensers concerned with that channel should be exact.
- (e) Bypassing channel selection: For the channel with thermoelectric device (TED), this option needs to be selected with designating channel number for the bypass signal.
- (f) Menu to add channel: Click 'Add' to add channel, or click 'Cancel' to close the channel setting window without adding channel.



Example setting of TED setting



③ Setting of origin: Origin location of TW-CC can be set by changing the distances from the hardware home coordinates of 3-axis robot (hardware limits of movable range). After changing origin setting, initialization must be executed, and loaded patterns in printing sequence must be edited for the coordinates.update

④ Setting of softlimit: Softlimit of TW-CC can be set by changing the distances from the hardware home coordinates of 3-axis robot (hardware limits of movable range).



Coordinate of current positions in Manual Control show the relative coordinate to user-defined origin while the user-defined softlimit coordinates are not relative to origin but relative to hardware home coordinates of 3-axis robot.

⑤ Setting of robot speed: The speed of robot can be set between 0 - 10 mm/sec. If the setting value is higher than 10 mm/sec, TW-CC uses maximum speed of 10 mm/sec automatically.

⑥ Information of controller(s): Information of controller(s) such as model number, serial number, or etc. is shown.

⑦ Setting of robot motors: These setting values are used for conversion between the thread of step motors and the unit of millimeter. Use these settings must be same with hardware spec.

⑧ Save button: By clicking this button, updated setting values are saved in a setting file, and the values can be loaded the next execution of TW-CC. Without clicking this button, updated setting values are valid for present execution, but not loaded the next execution of TW-CC.

How-to-use

■ Reading external .crd or .lst file

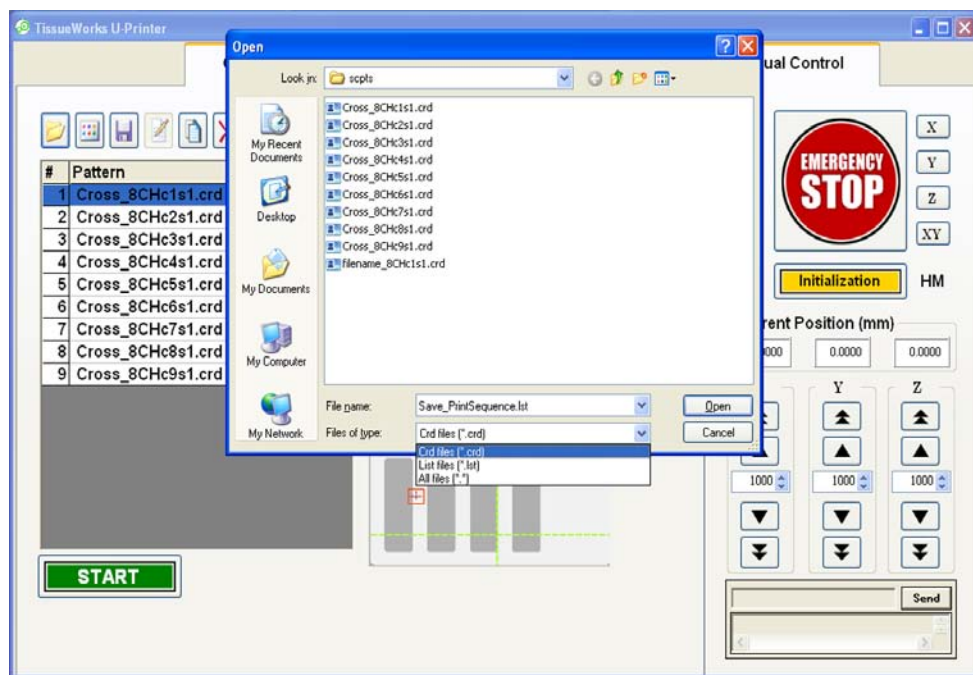


Load external pattern files (.crd) or previously saved list files (.lst)




.crd files are the files with extension of '*.crd'. These files are created by the TW-Nexus. TW-Nexus imports and convert grayscale bitmap image files (.bmp) into printable files containing spatial coordinates for the printing. The .crd files contain the coordinate information, the size of the pattern, channel, layer, and resolutions of printing. Multiple .crd files can be loaded into TW-CC.

.lst files are the files with extension of '.lst'. These files are created by user in TW-CC and having the coordinated information of all patterns in saved printing sequence. 'Files of types' needs to be changed to see crd files or lst files selectively.

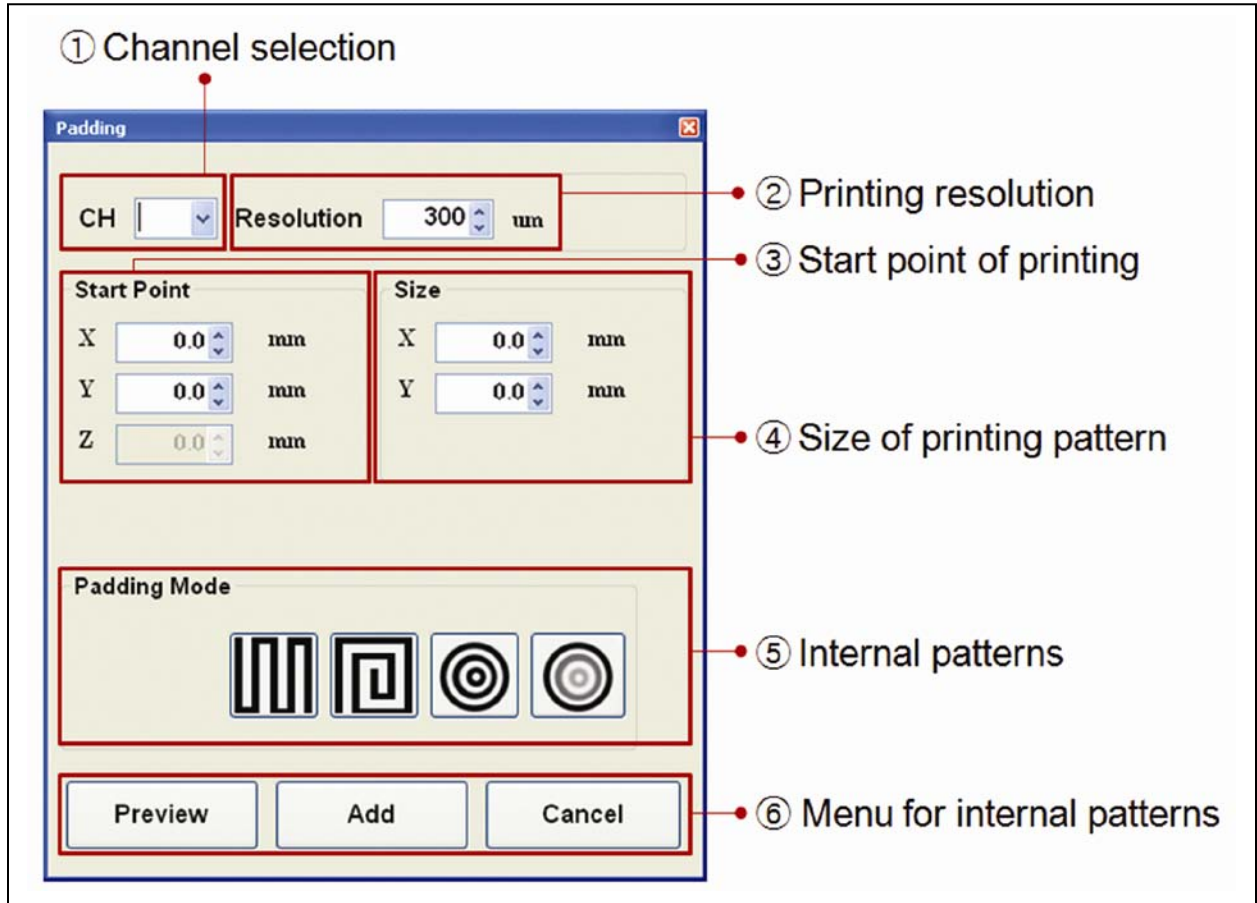




.lst files are created by saving the printing sequence of the TW-CC using icon.

■ Use of Internal Pattern

The window below appears by clicking  icon.

□ Component of windows for the internal patterns

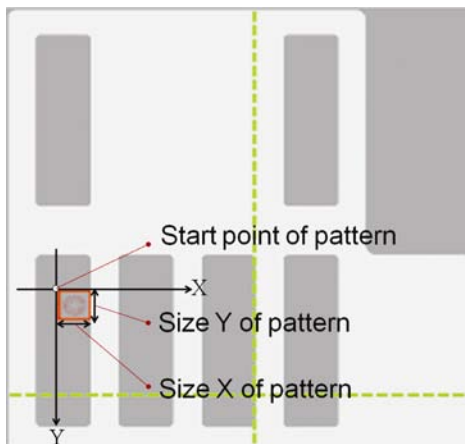


 After adding internal patterns to a printing sequence, you can open this setting panel of the internal patterns using  edit button and change all options.

① Channel selection: printing channel is designated by selection of channel number.

CH		▼
Start	1	▲
	2	
	3	
X	4	≡
	5	
Y	6	
	7	
Z	8	▼

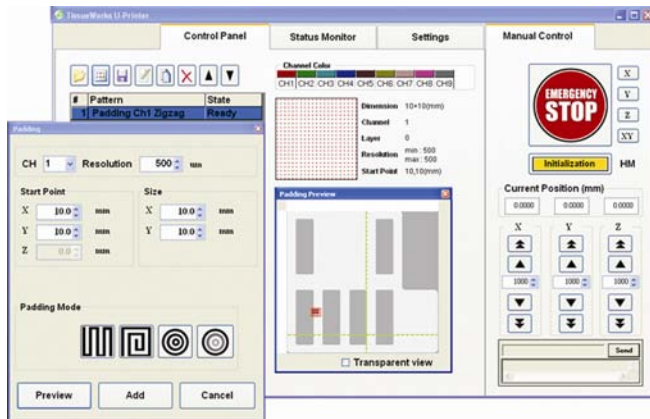
- ② Printing resolution: In 3D BP, the printing resolution is defined as inter-dispensing distance of droplets. Maximum printing resolution is 50 μm .
- ③ Start point of printing: Upper left point of each pattern is defined as start point. See the example figure below.
- ④ Size of printing pattern: maximum length of x and y in each pattern are defined as size X and Y respectively. See the example figure below.



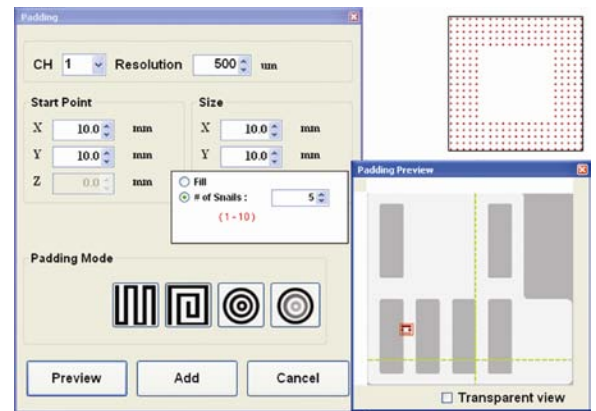
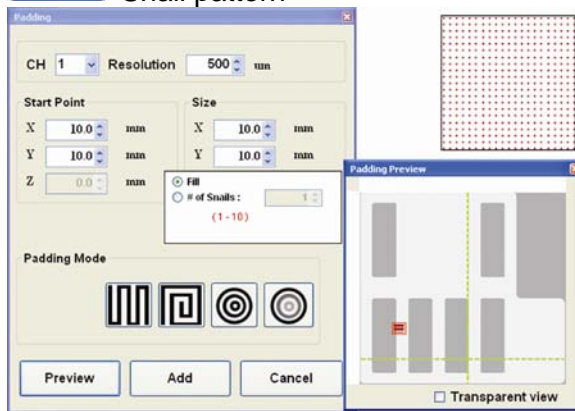
- ⑤ Internal patterns: Four different patterns of Zigzag, Snail, Circle, and Gradient Circle are pre-defined in TW-CC.



Zigzag pattern

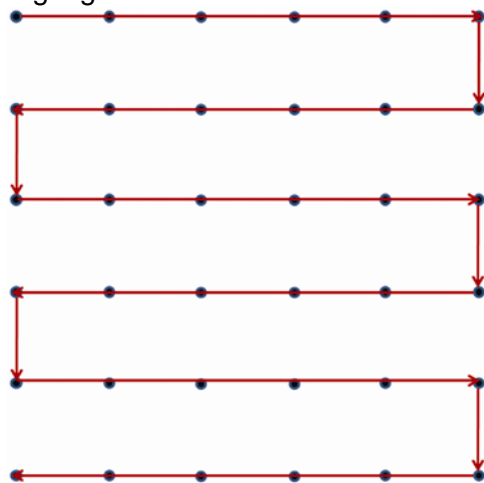


Snail pattern

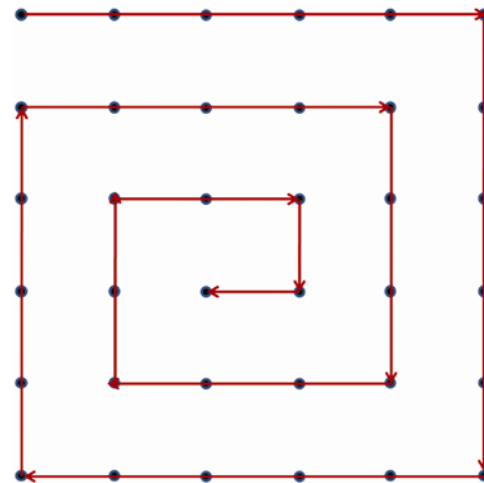


The printing path is different between zigzag pattern and snail pattern. The printing path may affect the morphology of printed hydrogel scaffold.

Zigzag of 6 x 6

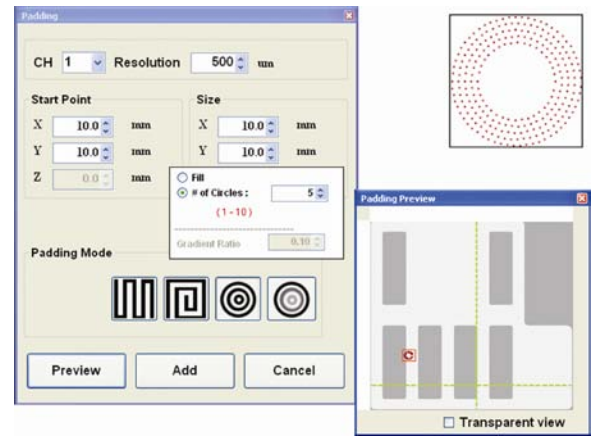
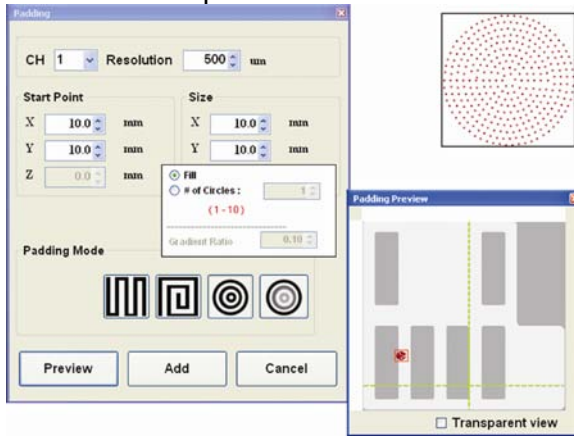


Snail of 6 x 6

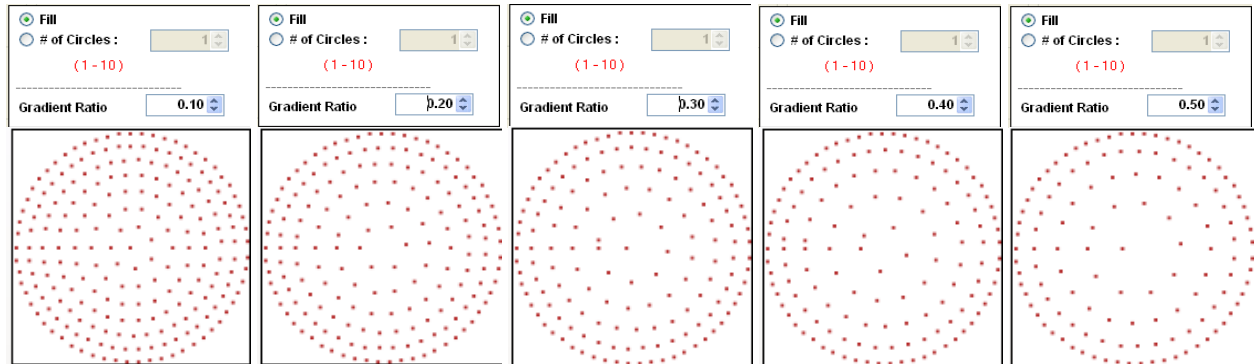




Circle pattern



Gradient circle pattern



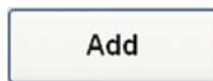
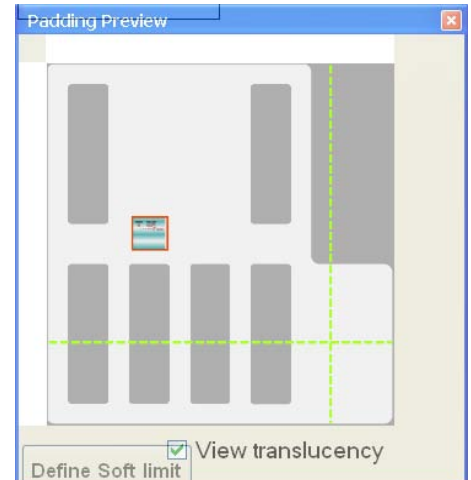
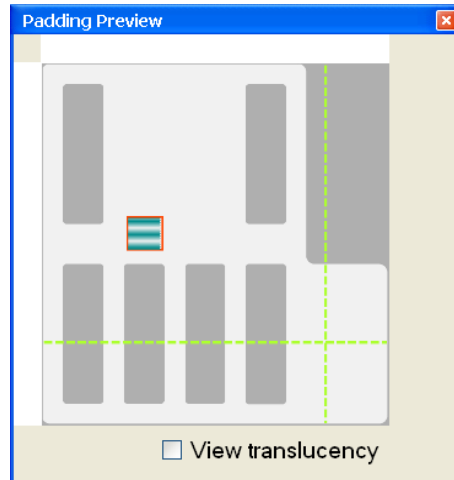
⑥ Menu for internal patterns



By clicking preview button, you can preview the shape of the pattern and its relative location on the vertical target substrates.

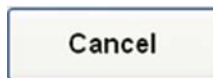


In the preview window, you can change the transparency of the patterns by selecting View Transparency. This option is useful when comparing the relative starting points and size between the layers and patterns.



By clicking Add button, the selected pattern is added in the printing sequence.

	Name	State
1	Padding_Ch1_Zigzag	Ready
2	Padding_Ch2_Snail	Ready
3	Padding_Ch3_Circle	Ready
4	Padding_Ch4_Gradient	Ready



By clicking Cancel button, the internal pattern setting window is closed without adding the pattern to the printing sequence.

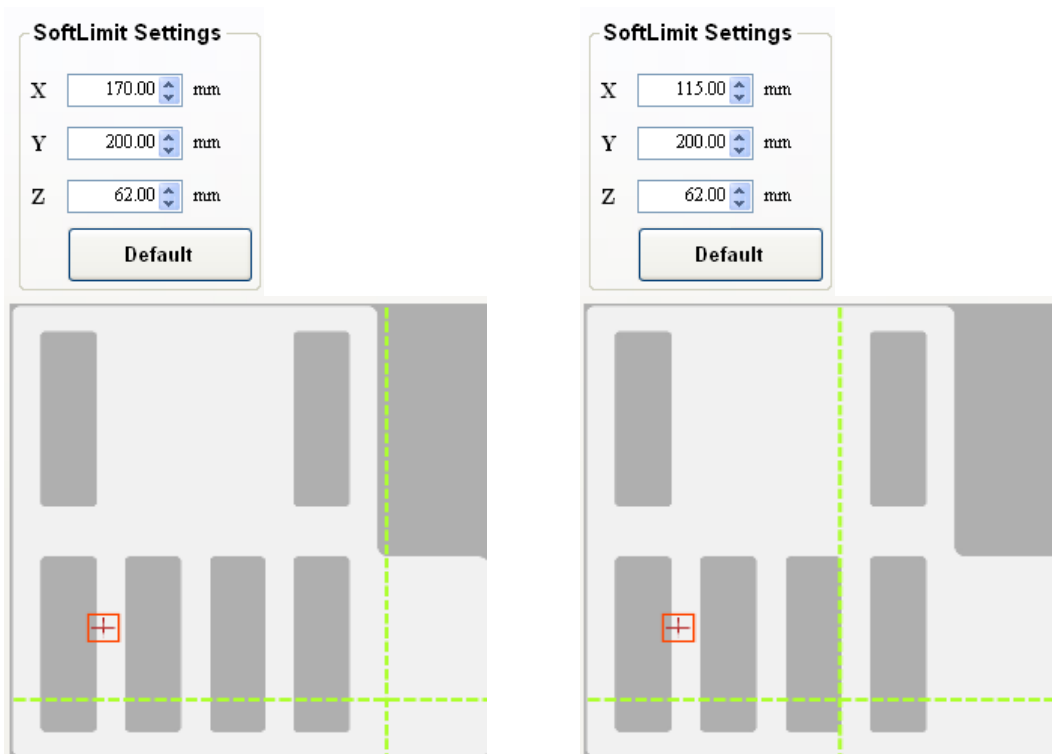
■ Defining the Soft Limit



TW-CC has the function of Soft Limits, which limits the movable range of robot arms. User of 3D BP can define the soft limit in TW-CC settings panel.



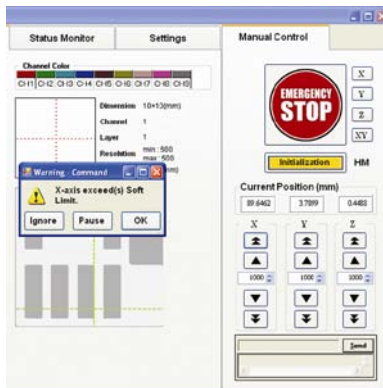
Two perpendicular lines on printing preview located in the Control panel indicate the user-defined soft limits of X and Y movements. Soft limit of Z axis is not shown, but can also be defined.



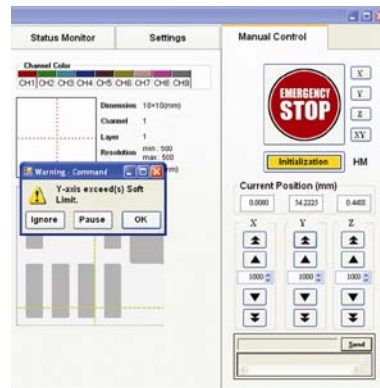
By changing the softlimit of X axis, the green line location on preview panel is changed.



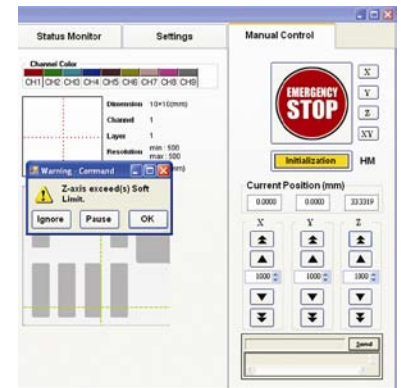
If the robot exceeds the soft limit (by manual movement), the robot is stopped, and promptly generate the following warning window. If you click **Ignore**, it will continue its printing or movement. If you click **OK**, the robot will be remained paused, and you can redefine the soft limit or manually move the robot to a desired location.



X axis over the limit



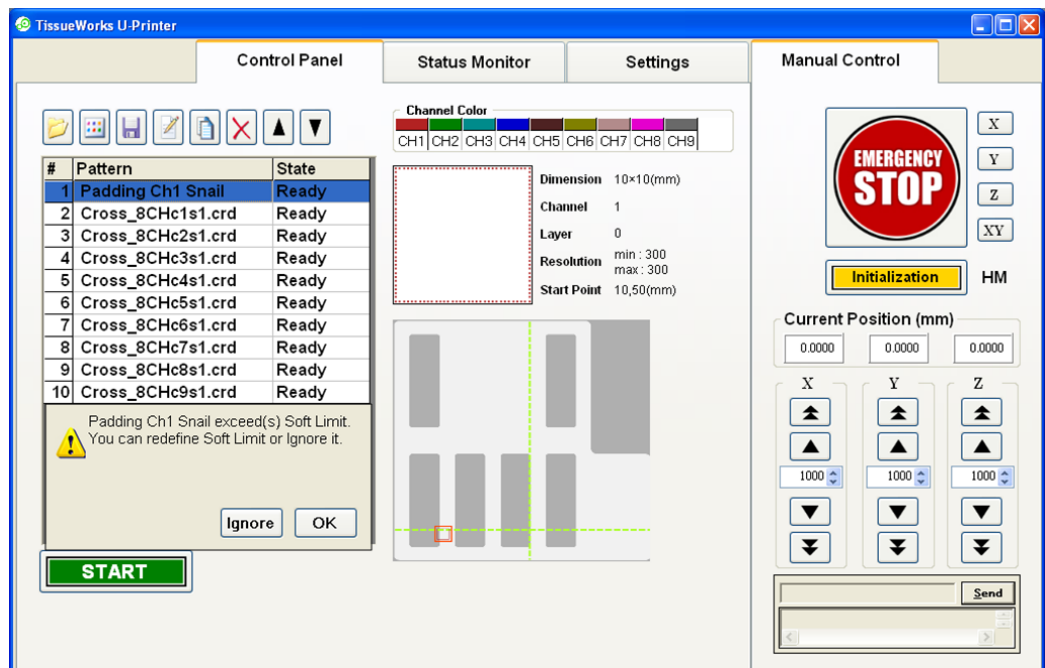
Y axis over the limit



Z axis over the limit





Before TW-CC starts printing, it automatically checks the locations of patterns in printing sequence. If any patterns are out of the soft limit range, then warning window is shown and 3D BP is paused. Click **Ignore** to ignore the soft limit and continue the loaded printing sequence. If you click **OK**, then you can redefine the soft limit or edit the pattern in the sequence and restart the printing.




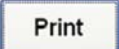
■ Printing

□ Start Printing/Pause/Stop

Start Printing

1. After adding a printing pattern to the file list, adjust the order, and click the  button on the Control Panel, or click the  button on the Status Monitor.
2. The status of the first file in the list will turn to “Running” and printing will commence.

Pause Printing


1. To pause, click  button in the Status Monitor.
2. The status of the file will be turned to “Pause”, and printing motion will temporarily stopped.
3. Click  button to restart the printing.

Stop Printing

1. In order to stop printing, click  button in the Status Monitor.



In case of emergency, you can press the Emergency Stop button. It has the same effect of the Stop printing button.

2. The status of the file will be turned to “Stop”, and printing motion will stop.
3. By clicking  button, the printing is restarted from the first file in the loaded printing sequence.

□ Adjusting the printing sequence

It is advised to adjust the printing sequence prior to start of the printing.





The adjustment of files that are in “ready” status is possible during printing and paused printing.

1. First, click the file to be reordered from the Control Panel.



Reordering the printing sequence is only possible from the Control Panel window.

2. You can reorder the printing sequence using buttons of  and .
3. Repeat the process until the desired file order is achieved.