Vinten RADAMEC
BROADCAST ROBOTICS

free-d

Installation Manual V1.4.4

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1 Introduction

1.1 Virtual sets

A key component of any virtual studio system is a means of measuring the precise position and orientation of each studio camera. This data is used to render the virtual scene from the appropriate viewpoint.

A camera tracking system must allow unrestricted movement of many studio cameras while panning through 360 degrees, work with a wide variety of camera mountings including manual pedestals, cranes, and hand-held cameras. The measurement of position and orientation of the camera must be to an accuracy that ensures precise matching of the real and virtual worlds. It should place no significant constraints on either the scene content or the studio environment. *free-d*™ satisfies all of these requirements.

1.2 *free-d*™

Developed by BBC R&D, this system uses a number of targets placed out of shot above the studio lighting grid. The targets are composed of concentric black and white retro-reflective rings forming a type of barcode. Each target has a unique code number, and is mounted at one of two different heights for optimum performance.

A small Target Seeking Camera (TSC) mounted on each studio camera views these targets. The TSC is mounted rigidly with its optical axis at right angles to the optical axis of the studio camera. A ring of LEDs surrounds the lens of the TSC. They illuminate the retro-reflective ceiling mounted targets.

The data from the TSC is passed to a purpose-built hardware unit, (*free-d*™ processor) which calculates the precise position and orientation of the studio camera in real time. *free-d*™ identifies the targets, measures their position to sub-pixel accuracy, and reads their barcodes. The position and orientation of the camera can then be computed.

The studio camera's zoom and focus are measured using conventional mechanical sensors. These data are multiplexed with the signal from the auxiliary camera. *free-d*™ outputs an RS422 signal that contains camera X, Y, height, pan, tilt, roll, zoom and focus data. Using this data output, the virtual set system will then create a background very accurately matching the position of the real camera, to within 1mm.

2 System components

Supplied items:

Part Number	Description
101-072-0002	*free-d*™ Target Seeking Camera (TSC)
Various	Camera adapter bracket (to attach TSC to studio camera)
012-037-0020	TSC power cable (standard length 20m)
195-112-0002	TSC power supply
177-072-0001	*free-d*™ Processor
Various	Lens encoder
N/A	Mains cables (2 per camera system)
Various	Upper and lower targets (of roughly equal quantity)
N/A	3.5 inch floppy disk containing *free-d*™ lens calibration

Required items not supplied:

- Genlock source (if Free-d unit is not polled by VR system)
- Genlock video cable
- TSC video cable (length as required)
- Oscilloscope (for calibration purposes only)
- NTSC composite video monitor (for calibration purposes only)
- PC laptop* (for calibration purposes only)
- RS422/232 converter* (for calibration purposes only)
- 9 way pin-to-pin D-type serial cable* (for calibration purposes only)

Note: items marked with * will be provided by the Vinten Radamec Engineer for the duration of the on-site system commissioning.

3 Installation

3.1 Targets

The targets supplied will come with drop rods, but not necessarily horizontal mounting bars. It is normally required that the customer or system integrator source and supply these bars and a means to mount the bars to the ceiling. A dedicated grid is the best method of securing the target bars. It is essential that whatever method is employed, the target array must be secure and vibration free.

The optimum pattern of high and low targets can be seen in Appendix G. This is an optimum pattern only; it is designed so that the maximum number of targets will be identified, with the minimum number of low targets obscuring high targets. For ease of installation and calibration, this pattern should be observed while installing the targets on the studio ceiling.

However, if there are any obstructions in the ceiling preventing the mounting of a high target (eg, ducting, air-conditioning units) then a low target will suffice. The major objective when installing targets is to ensure that a roughly equal number of high and low targets can be seen by the Target Seeking Camera in any position in the studio.

The optimum distance between each target is studio height dependent, and will be advised by the Vinten Radamec Project Manager.

Whilst installing the targets, note the identification number located on the back of the target on the target map. This will significantly expedite the calibration process.

3.2 Lens encoder

Single module dimensions	136mm x 45mm x 70mm
Weight (pair)	1 kg approx.
Encoders to lens gearing	24 : 1
Output signals	1024 pulses / rev of encoder
Electrical connection	1m flying lead to 26 way 'D' type.

Always fit the protective cap to the studio lens during installation of the encoder. Remove the two screws that secure the cover of the drive module. Lift the cover off.

Remove the two hex-socket screws that secure the module to the mounting block adapter plate. Take care not to damage any internal components when removing the module. Slacken the two screws that fasten the focus section to the zoom section.

Remove the two screws and lock washers from the mounting block, then fit the block to the lens. Do not over tighten the mounting screws. Check that both zoom and focus elements are not obstructed and move freely after fitting the mounting block.

CAUTION
IT IS ESSENTIAL THAT ONLY THE SCREWS AND WASHERS SUPPLIED ARE USED. INCORRECT LENGTH SCREWS CAN PERMANENTLY DAMAGE THE LENS.

Fit the module in position the mounting block with the zoom section in mesh with the zoom gear ring of the lens and estimate how far its gear is out of mesh with the zoom gear ring. Remove the module and extract the spacer shim from between the adapter plate and the mounting block. Peel off an amount from the spacer (each shim is 0.05 mm, 0.002 inch thick) that is equal to, or less than, the amount estimated to bring the gears into mesh. Re-fit the module and repeat the procedure until the gears mesh correctly.

NOTE
CORRECT MESH IS VERY IMPORTANT AS TIGHT SPOTS WILL RESULT IN POOR PERFORMANCE.

Check the mesh at several points while rotating the lens gear ring from end to end and ensure that a small amount of backlash can just be felt at the tightest point.

Adjust the mesh of the focus section with the focus gear ring of the lens and tighten the two screws that fix it to the zoom section. Check the mesh at several points whilst rotating the focus gear ring from end to end and ensure that a small amount of backlash can just be felt at the tightest point. Readjust the focus mesh until this is satisfactory.

Do not lubricate the output gear/lens ring. Check end-to-end operation of both zoom and focus. When satisfactory, re-fit the encoder module cover.

3.3 Target seeking camera

Dimensions	100mm x 82mm x 82mm
Weight	1.5 kg
Lens	Pentax, Ref. C30811 (C-mount)
Output signals	Serial digital video (NTSC)
Connectors	BNC – video output BNC – genlock input 26w ‘D’ – Lens encoder input 2x9w ‘D’ – Power Input 15w ‘D’ – RBU input

The Target Seeking Camera (TSC) is intended to mount rigidly to a studio camera, perpendicular to the optical axis. It will normally mount in place of the viewfinder, either above the lens at the front of the camera or at the rear if hand-held operation is required. Custom-designed mounting brackets are normally supplied to suit the cameras in the studio. The base of the TSC can be adjusted to ensure that is as near as possible to perpendicular to the studio camera optical axis.

The view of the targets should be unobstructed (for example by any part of the camera operator’s body) and should not make operating the studio cumbersome or make it difficult to balance. The offset between the two cameras must be known so that the system can compensate during calibration.

The TSC will need to be genlocked if the virtual set system software is not polling the *free-d*™ processor. Contact your virtual set vendor for verification.

3.4 *free-d*™ Processor unit

Dimensions	483mm x 43mm x 500mm (19inch, 1U, 500mm)
Weight	8.5 kg approx.
Input signals	Serial digital video, RS422/RS485 control data
Output signals	Analogue video, RS422/RS485 camera data System normal relay
Power Supply	85 to 265 volts AC, 47 – 440 Hz, 5A

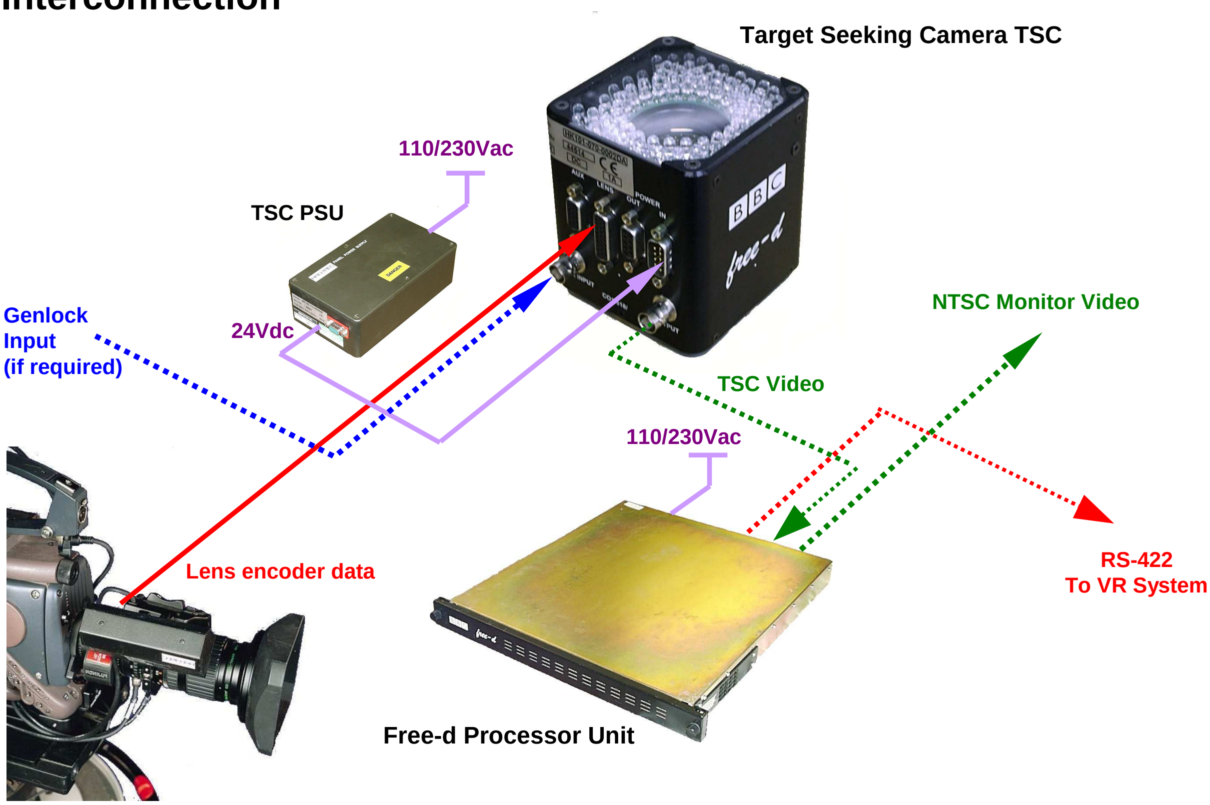
The *free-d*™ Processor Unit receives a serial digital video signal from the TSC which contains both the image of the targets as viewed by the auxiliary camera and encoded values of the zoom and focus (which are measured by conventional mechanical sensors). The 19 inch rack-mountable unit identifies the targets in the image, measures their positions to sub-pixel accuracy and reads their bar codes. Knowing the positions of each target in the studio, which are stored in non-volatile memory, the position and orientation of the camera can be computed.

The unit generates an RS422/RS485 serial data stream, which conveys the position, orientation, zoom, and focus data to the virtual set system.

There is a BNC connection available to monitor the operation of the TSC. Monitoring of this NTSC signal will be required during calibration.

On initial installation the default control parameters should be loaded into the *free-d*™ Processor Unit. This can be achieved by operating the card switches in the following sequence: Hold RESET (S1), hold STORE (S4), release RESET, wait until self-tests are complete, release STORE. The default parameters may then be stored in the unit's non-volatile memory by another operation of the STORE switch.

4 Interconnection

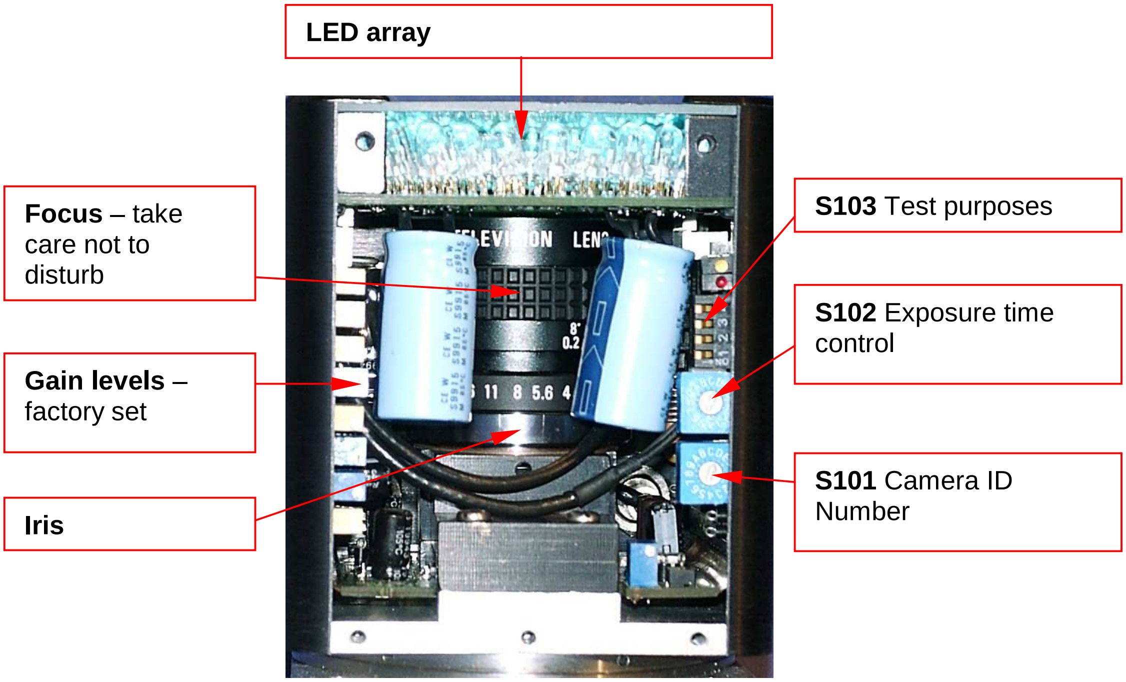


Cables indicated by a dotted line are not supplied with the Free-d system.

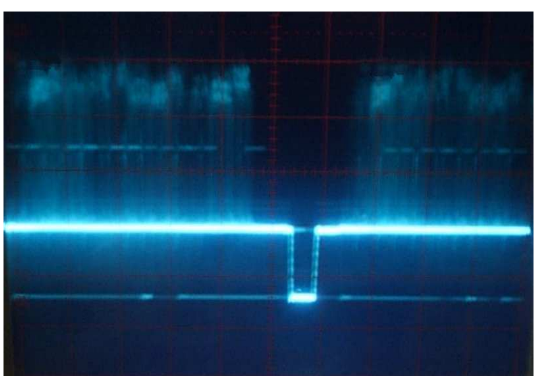
When connecting the *free-d*™ processor to the calibration PC, an RS-422/232 converter will be required and a direct, pin-to-pin cable, 9-way male D-type to 9-way male D-type. The SDL cable to connect the *free-d*™ processor to an Onyx, Onyx2, Xync interface or Virtual Scenario SCU should be made as follows:

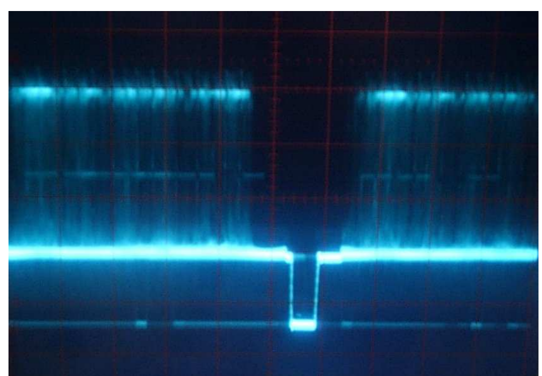
free-d™	Onyx	Onyx2	Xync Interface	Virtual Scenario
9-way male D-type	9-way female D-type	9-way female D-type	25-way female D-type	9-way male D-type
2 Tx-	2 Rx-	2 Rx-	15 Rx-	5 Rx-
8 Rx-	3 Tx-	3 Tx-	14 Tx-	9 Tx-
3 Rx+	7 Tx+	4 Tx+	2 Tx+	8 Tx+
7 Tx+	8 Rx+	6 Rx+	3 Rx+	4 Rx+

5 Camera optimisation

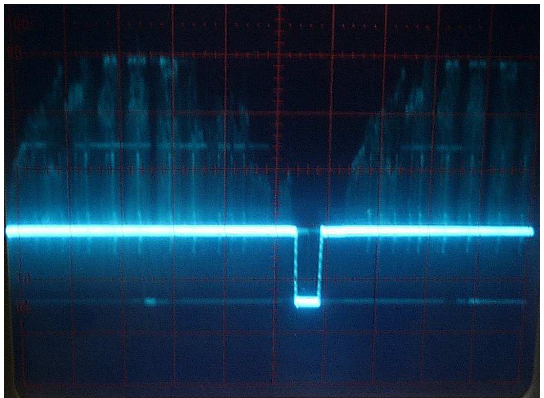


Set the camera ID number using rotary switch S101 (see Appendix D). Place the *free-d*™ TSC at its lowest operating height (in most cases this will be with the studio camera on the floor) so that it has an unobstructed view of the targets. Switch off any house lights in the field of view of the camera. Observe the monitoring video output from the *free-d*™ Processor on both a picture monitor and on an oscilloscope triggered at TV line rate. The video level of the brightest targets should be close to peak white (0.7 Volt) but without any clipping. If this is not the case, it will be necessary to adjust the iris of the *free-d*™ TSC; **take extreme care not to disturb the focus**.

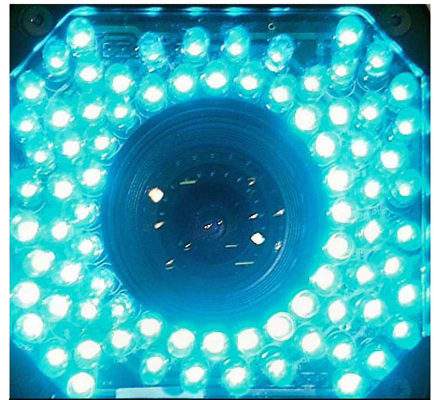

Optimised – uniform amplitude, no clipping


Clipping – bright peaks indicate video level saturation

Check on both the NTSC monitor and the oscilloscope that all the targets in view have approximately the same video level (the dimmest target should have a video level no less than 70% that of the brightest target). If the brightness is less uniform than this, it will be necessary to adjust the 'aiming' of the illuminating LEDs.

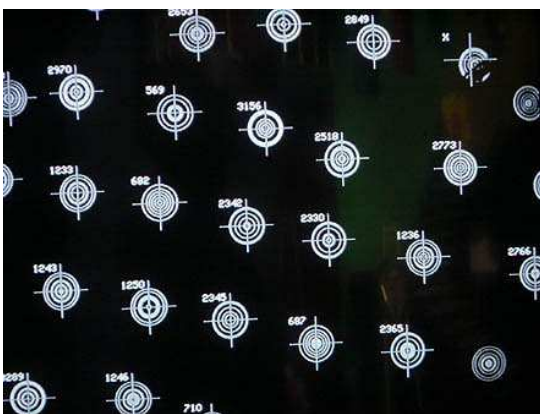


Badly aimed LEDs – centre targets brighter than outer targets.



free-d™ TSC top-view LEDs after aiming.

Check that most of the targets that can be seen in the image are being recognised by the system and are annotated with their barcode numbers.



free-d™ Processor monitor output

If any target barcode values are missing (or are replaced with a x or **+** symbol), and there is no obvious reason such as the target being partially obscured or damaged, suspect that the focus is not correctly set for the studio height. If it is necessary to change the focus, even slightly, it is **essential** that the *free-d*™ camera be re-calibrated afterwards.

To maximise the depth-of-field, ensure that the exposure-time control (S102) is set to position 'D'; this is the position where the LED array appears to be brightest.

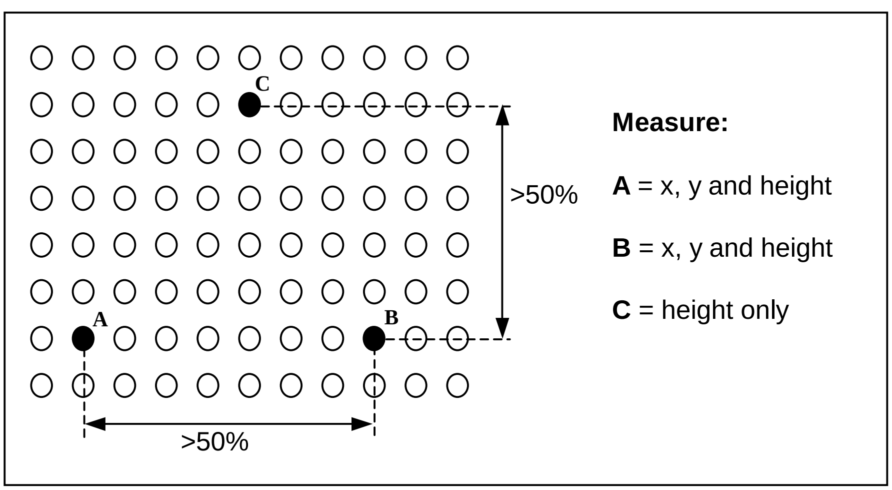
If high-speed camera movements are anticipated, it may be desirable to reduce the exposure time. See appendix E.

6 Calibration procedure

Before proceeding, ensure that all required targets have been mounted in the studio ceiling and the identification number of each target number noted onto the map (see Appendix G). If no target map is available, it will have to be reconstructed by directing the Free-d camera at the target array, and reading the target ID numbers from a monitor connected to the monitor output of the processor.

Select a suitable studio reference point. This reference (or zero) is typically the bottom left target on the target map (Row1, Column 1). In actuality the reference point can be any permanent reference in the studio. If there is a 3D virtual set system already in operation in the studio then it may be more convenient to use the same reference as the VR set.

Measure three targets with respect to the reference. It is essential that these targets be measured to the best accuracy possible, as the results have a huge effect on the subsequent calibration. It is necessary to measure x, y, and height of two targets (A and B) and height only of a third target (C). The distance between targets A and B should be greater than 50% of the entire target array in the x-axis. This determines a baseline from which all other targets are measured. The distance from target C to the baseline should be greater than 50% of the entire length of the y-axis. If these rules are not adhered to, the Calibration Wizard will not proceed and the program will display a warning. The measured targets do not have to be on different rows or columns, and they do not have to be at different heights.



Note these measurements together with their ID number. These ID numbers will be entered in the calibration program (freed_v14.exe).

6.1 Constructing a target database

Once operational, the system must know the exact position of every target to an accuracy of less than 1mm. To measure every single target to this level of accuracy, while not impossible, would be difficult and time consuming. The calibration process is able to refine the target positions provided an initial accuracy of 100 mm is achieved.

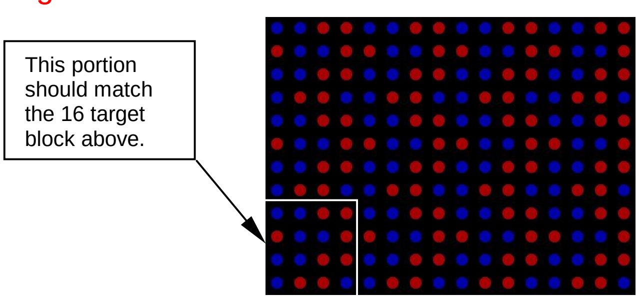
Provided the precise position of the three measured targets is determined, the system will refine the position of all the others.

Run the program ***makedef.exe***. This creates a text file containing x,y,z values based on the installed grid pattern. When prompted input the x, y spacing and number of targets for each direction, height of upper and lower targets, min x and y values from origin (an offset of x, y, normally 0.0 for each) and the pattern of high and low targets used.

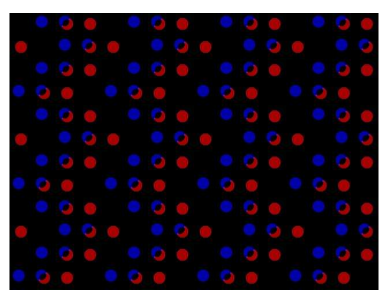
The pattern is defined by a hex word. The whole pattern can be calculated by knowing the configuration of the first block of 16 targets (4x4) situated in the bottom right-hand corner of the target map.

Row 4	Low = 0	Low = 0	High = 1	High = 1	= 3 in Hex
Row 3	High = 1	Low = 0	Low = 0	High = 1	= 9 in Hex
Row 2	Low = 0	Low = 0	High = 1	High = 1	= 3 in Hex
Row 1	Low = 0	High = 1	High = 1	Low = 0	= 6 in Hex
	Col 1	*Col 2*	*Col 3*	*Col 4*	**Byte Word = 6393**

To view and check the pattern byte word, run the program ***seepatt.exe*** and enter the pattern to be used in hex (in this case 6393). Blue = Low, Red = High.



Target pattern hex “6393”



Tilt/roll simulation

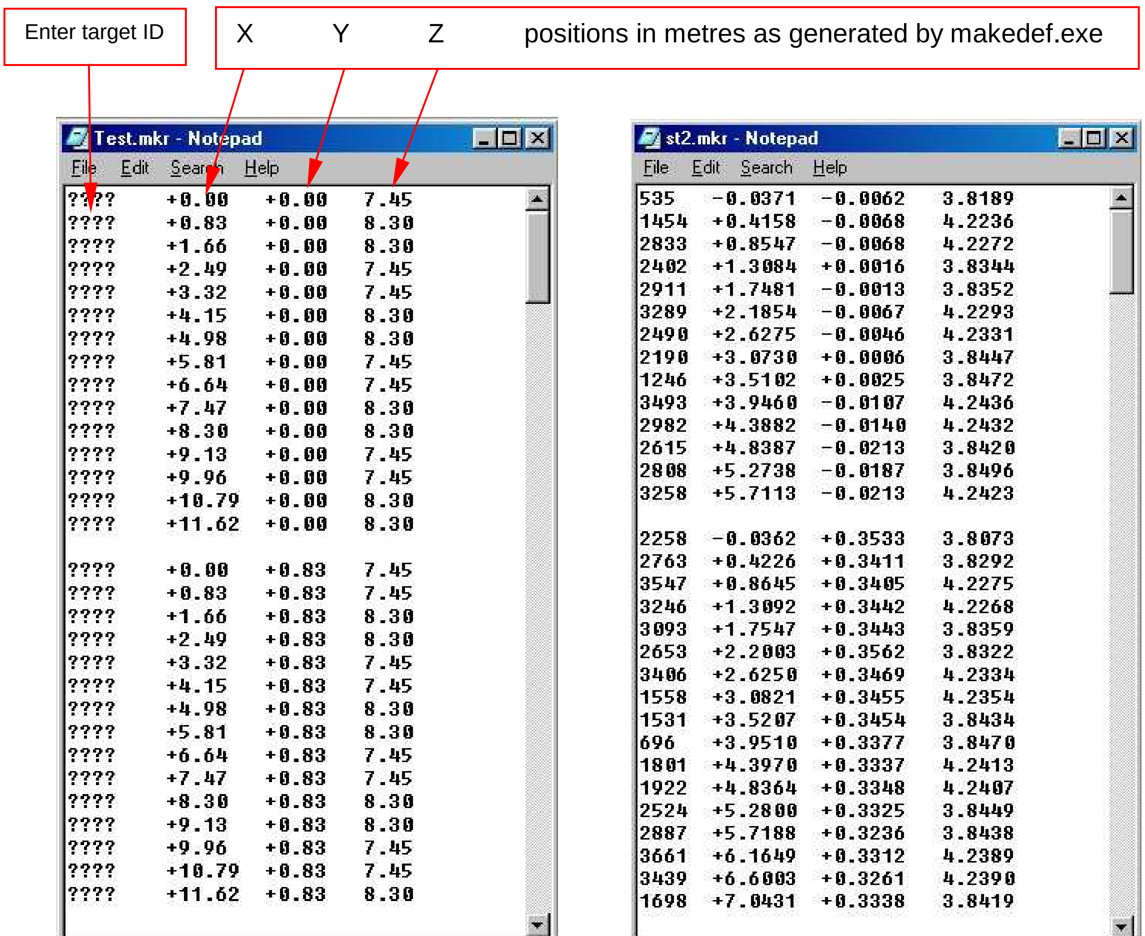
Use the cursor keys to simulate tilt and roll of the camera to see the extent of low targets obscuring high targets.

Makedef.exe will create the ***name.mkr*** file for you to edit with rough estimations of each target position. This file is essentially a text file and can be edited in Notepad or alternatively in ***Freed_v14.exe*** in:

Utilities→Edit Target Data (Alt-U-E)

Enter the target numbers according to the target map. If there is no target then enter "***????***" for the target ID. If major changes in positioning are necessary, but target numbers have already been entered, global changes (x, y, z or rotation) can be made to the ***name.mkr*** file in ***Freed_v14.exe*** in:

Utilities→Change Coordinates (Alt-U-C)



????	+0.00	+0.00	7.45
????	+0.83	+0.00	8.30
????	+1.66	+0.00	8.30
????	+2.49	+0.00	7.45
????	+3.32	+0.00	7.45
????	+4.15	+0.00	8.30
????	+4.98	+0.00	8.30
????	+5.81	+0.00	7.45
????	+6.64	+0.00	7.45
????	+7.47	+0.00	8.30
????	+8.30	+0.00	8.30
????	+9.13	+0.00	7.45
????	+9.96	+0.00	7.45
????	+10.79	+0.00	8.30
????	+11.62	+0.00	8.30
????	+0.00	+0.83	7.45
????	+0.83	+0.83	7.45
????	+1.66	+0.83	8.30
????	+2.49	+0.83	8.30
????	+3.32	+0.83	7.45
????	+4.15	+0.83	7.45
????	+4.98	+0.83	8.30
????	+5.81	+0.83	8.30
????	+6.64	+0.83	7.45
????	+7.47	+0.83	7.45
????	+8.30	+0.83	8.30
????	+9.13	+0.83	8.30
????	+9.96	+0.83	7.45
????	+10.79	+0.83	7.45
????	+11.62	+0.83	8.30

Example .mkr file generated by makedef.exe

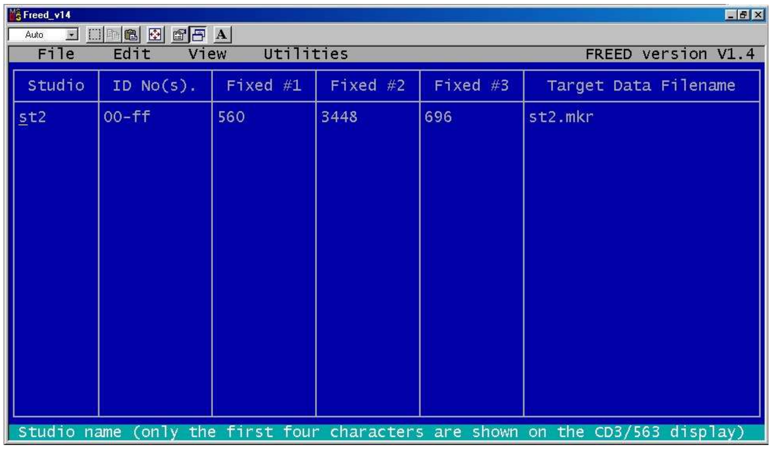
535	-0.0371	-0.0062	3.8189
1454	+0.4158	-0.0068	4.2236
2833	+0.8547	-0.0068	4.2272
2402	+1.3084	+0.0016	3.8344
2911	+1.7481	-0.0013	3.8352
3289	+2.1854	-0.0067	4.2293
2490	+2.6275	-0.0046	4.2331
2190	+3.0730	+0.0006	3.8447
1246	+3.5102	+0.0025	3.8472
3493	+3.9460	-0.0107	4.2436
2982	+4.3882	-0.0140	4.2432
2615	+4.8387	-0.0213	3.8420
2808	+5.2738	-0.0187	3.8496
3258	+5.7113	-0.0213	4.2423
2258	-0.0362	+0.3533	3.8073
2763	+0.4226	+0.3411	3.8292
3547	+0.8645	+0.3405	4.2275
3246	+1.3092	+0.3442	4.2268
3093	+1.7547	+0.3443	3.8359
2653	+2.2003	+0.3562	3.8322
3406	+2.6250	+0.3469	4.2334
1558	+3.0821	+0.3455	4.2354
1531	+3.5207	+0.3454	3.8434
696	+3.9510	+0.3377	3.8470
1801	+4.3970	+0.3337	4.2413
1922	+4.8364	+0.3348	4.2407
2524	+5.2800	+0.3325	3.8449
2887	+5.7188	+0.3236	3.8438
3661	+6.1649	+0.3312	4.2389
3439	+6.6003	+0.3261	4.2390
1698	+7.0431	+0.3338	3.8419

Example .mkr file after system calibration

Note: always keep a backup of the original name.mkr file in case a restart is required.

6.2 *free-d*™ calibration wizard

Run the program **freed_v14.exe**. This is a menu-driven program with three main windows.

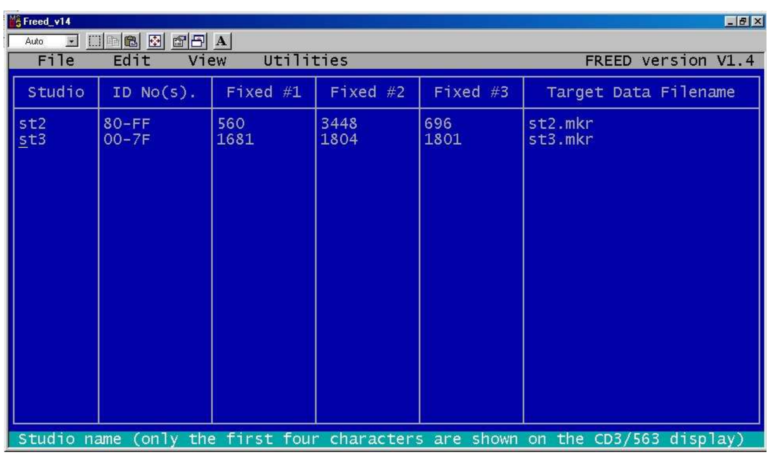


6.2.1 Studio list

Select: View→Studio List (Alt-V-S)

Enter a four-character name for the studio. This name is arbitrary and can be displayed on the Free-d processor display unit to check if the correct database is being used for the studio.

Enter the studio ID number (in hexadecimal). The *free-d*™ processor can store up to 256 different target databases (ie, up to 256 different studios). 0-255 in decimal equates to 00-FF in hexadecimal. If only one studio is to be calibrated it is advisable to enter studio ID as 00-FF. This will upload the calibrated database to all addresses in the database.

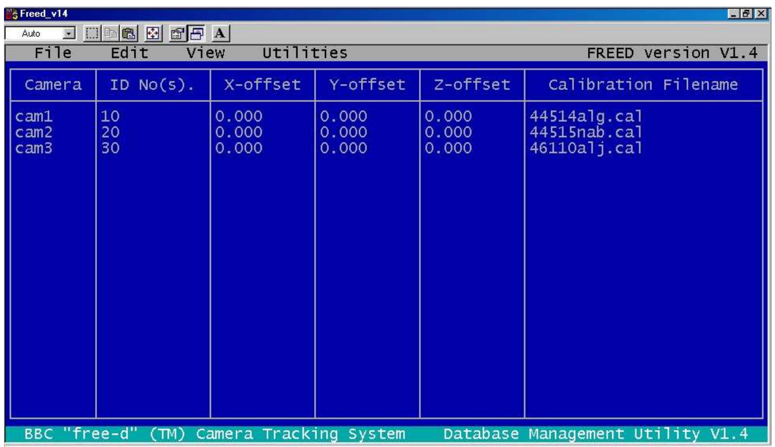


If two studios are equipped with *free-d*™ targets then addresses 00-7F and 80-FF could be used. Use switch S3 on the front of the processor card to increment or decrement the current studio database address. Please note that when changing from one target database to another, the displayed studio name can change instantly, but the actual system memory can take up to **5 minutes** to reconfigure. If the current database address is somewhere within the range 00-7F, it may take several deflections of switch S3 before the next range of addresses is accessed. Once the desired database has been located, the biased switch S4 should be deflected to save this setting after a system reset.

Enter the measured target numbers. Fixed #1 and #2 correspond to the targets where x, y, and height were measured. Fixed #3 corresponds to the target where only height was measured.

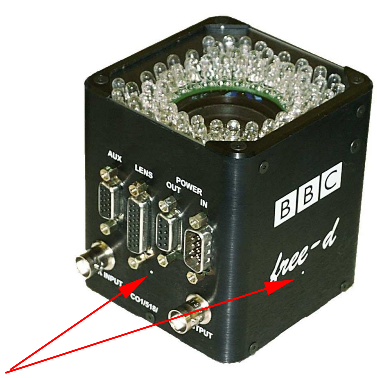
Finally, the ***name.mkr*** filename as created in the previous chapter must be entered in the “Target Data Filename” column.

6.2.2 Camera list



Select: View → Camera List (Alt-V-C)

Measure the offset (x, y, z) between the *free-d*™ camera and the broadcast camera optical centres and enter them into the relevant column.

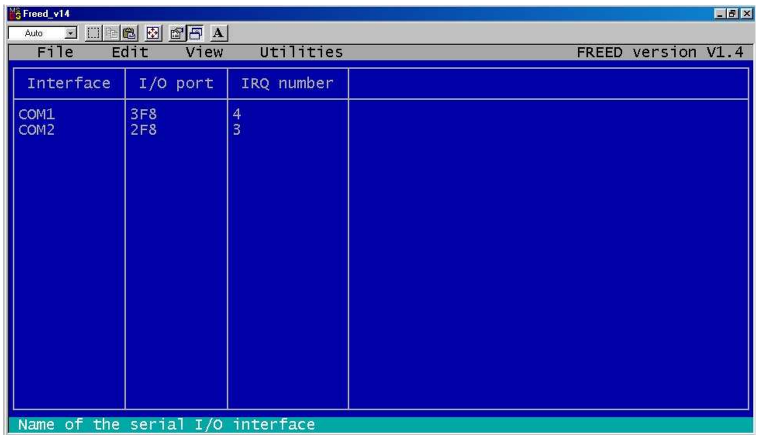


CCD centre is 30mm above white dot

The *free-d*™ camera offset measurements (in meters) consist of three axes. The X-axis offset should be 0.0 if the camera is mounted in the centre of the studio camera. The Y-axis is the distance from the centre of the studio lens to the centre of the *free-d*™ lens; this 30mm above the white dot printed on all sides of the camera. If the *free-d*™ camera is in front of the lens centre point the value should be entered as a negative number. Lastly, the Z-axis is the height of the dot from the centre line of the lens through the studio camera. This measurement should always be entered as a minus value, for example -0.130.

Enter the camera ID number (Cam No.1 = 10, 2 = 20), according to the switch setting on the TSC, and a four-character name for the camera (use cam1, cam2). This name can also be displayed on the processor unit to check if the correct camera calibration and offsets are being used. The camera calibration filename (**xxx.cal**) must also be entered in the “Calibration Filename” column. This file should be provided on floppy disk with the delivered system.

6.2.3 Interfaces



Select: View → Interfaces (Alt-V-I)

Enter appropriate I/O port and IRQ details. The following settings work with most PCs but they could vary in some cases.

Interface for COM1: I/O port = 3F8 and IRQ = 4
Interface for COM2: I/O port = 2F8 and IRQ = 3

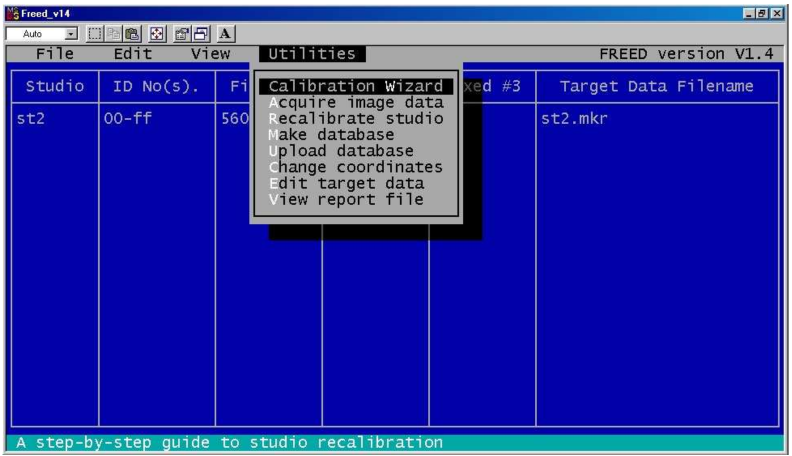
Select: Utilties → Make Database (Alt-U-M)

This will create a file called CD3_563.dat, which contains all the TSC information as well as the target positions.

Connect the PC/LAPTOP being used for calibration to the *free-d*™ processor unit via a serial data cable (pin to pin) and a 422/232 converter.

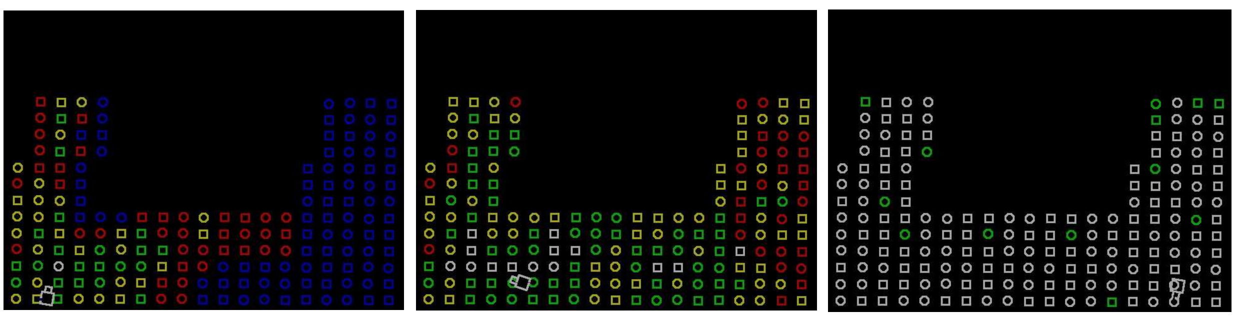
Select: Utilities → Upload Database (Alt-U-U)

This will upload the CD3_563.dat file into the processor unit.

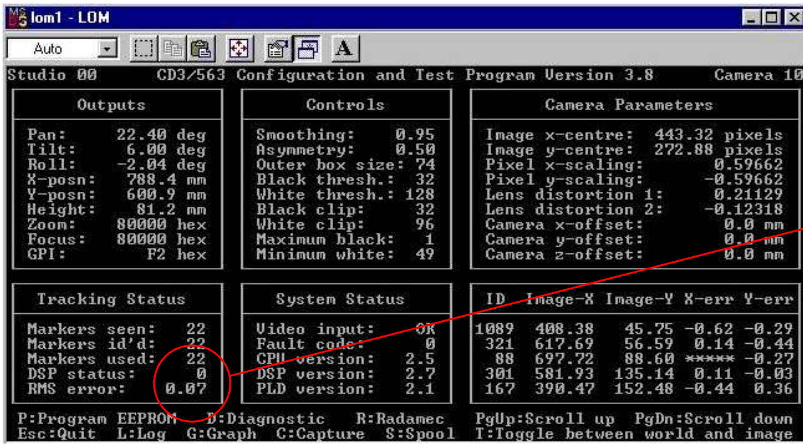


Select: Utilities → Calibration Wizard (Alt-U-W)

Follow the prompts and the PC will read back the target database from the processor and display it on the screen. The display shows a graphical representation of the target layout and when each target has been seen by the TSC from enough positions it will change colour from blue to red to yellow to green and finally to white. Move the camera around the studio to take as many views as possible of all the targets. The file called xxx**.raw** will be created containing a list of which targets were seen, frame by frame.

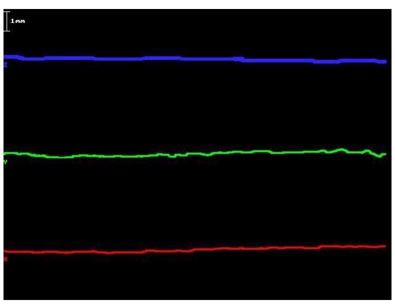


The wizard will automatically apply the **.raw** file to the **.mkr** file and adjust it by an iterative process to arrive at the real correct position of each target. The fixed (measured) target positions will not be changed but will be used as a reference for adjustment of all the others. A new **.mkr** file will be created and used to create a new database **.dat** file which will automatically be uploaded to the processor completing the calibration.



Ensure RMS error is less than 0.1

The file ***lom1.bat*** can be run on the calibration PC/laptop to check the system is working correctly**.** It shows useful diagnostic information including number of targets seen, targets used, rms error as well as position information output to the VR system. The rms error should ideally be in the region 0.05 to 0.10 and must always be less than 0.25. Anything above this will cause the yellow error light on the *free-d*™ processor card to illuminate and is considered a ***non-trivial*** problem.



Within the ***lom1.bat*** program is a graph facility that plots the fluctuation of measured x,y and z (height). Keep the *free-d*™ TSC stationary. Press "**G",** if the plotted lines are within the indicated "1mm" level, then the system is operating within specification whilst stationary. Further tests need to be performed for overall acceptance.

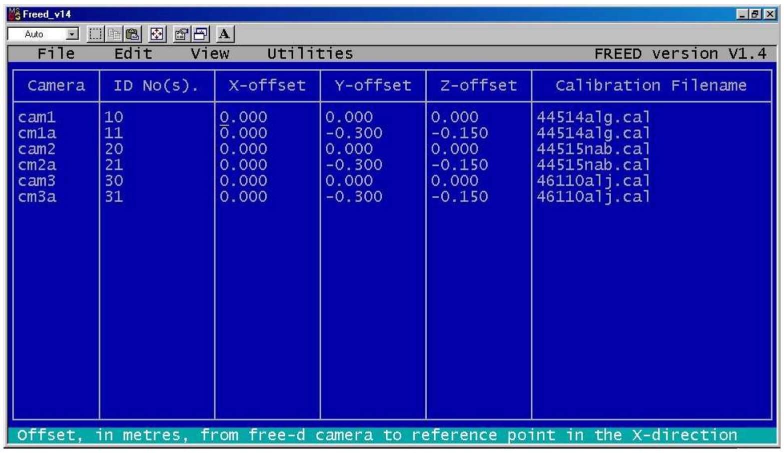
Calibration need only be carried out once, assuming none of the targets are subsequently moved. Should a target be accidentally knocked out of alignment, its position can be temporarily deleted from the database. This effectively removes any erroneous positions, which may introduce error had the target remained within the system calculations.

6.3 Additional *free-d*™ Processors

If more than one processor is being used, the additional units can be calibrated simply by uploading the final database via the laptop and cable from the ***freed_v14.exe*** program "utilities", "upload database" function as before.

6.4 Additional *free-d*™ Target seeking cameras

If more than one camera is to be used in a system it is possible to enter more than one set of camera values in the “camera list” section of the database. The *free-d*™ camera number will be recognised by the processor and relevant calibration files used. Therefore, any camera can be used with any processor, provided it has the database programmed into it. Aux camera number is changed using the rotary switch S101 to change the most significant bit of the camera number; eg, change the most significant bit (MSB) of the camera number from 10 to 20 by changing S101 from F to E.



Additional information in the “camera list” is also required if there are two possible mounting positions for the *free-d*™ camera. If this is the case a second row can be added in the camera list with a different name, ID number and the x,y,z offsets changed. The 15-pin hi-density D-type port on the *free-d*™ camera has 11 aux. inputs available, four of which can be used to set the lowest significant bit (LSB) of the camera number.

Uploading the database again will enable different offsets to be applied when the camera ID number is changed; eg, change the LSB of the ID number on the *free-d*™ TSC so camera 10 will become 11.

To use the aux. inputs on the *free-d*™ camera a connector must be made up and the relevant pins linked together. Pins 4, 14, 10 and 5 are used to set the LSB of the camera number. For example, if no aux. inputs are connected then camera n would be n0. If pin 4 is connected to pin 15 (0V) then it becomes n1.

Camera ID	Pin connections on Aux. Connector
n0	None
n1	4 to 15
n2	14 to 15
n3	10 to 15
n4	5 to 15

7 System verification

This chapter describes a set of tests to confirm that a *free-d*™ installation is correctly set up. Some of the tests are performed on the camera tracking system in isolation, and others on the tracking system in conjunction with the associated Virtual Set system. The order of the tests has been chosen to minimise the extent to which one test depends on the result of a later test, so **they should always be carried out in the specified sequence**.

7.1 RMS error

Observe the RMS error reported by the *free-d*™ system (this can be displayed on the CD3/563A by selecting position ‘2’ on rotary switch S5, and setting toggle switch S3 ‘right’). The value displayed should be less than 0.10 for all positions and orientations of the camera, although the value may momentarily increase while the camera is moving.

If the indicated value is greater than or equal to 0.10, suspect that the *free-d*™ camera (particularly the focus) has been disturbed since it was calibrated, that the camera ID number has been changed (causing the wrong calibration file to be selected), that the appropriate camera calibration file has not been uploaded, or that one or more of the targets has been disturbed since the studio was calibrated.

7.2 Levelling

With the studio camera mounted on a pedestal, and with the pan and tilt locked, observe the height (Z) value reported by the *free-d*™ system as the camera is moved around on the (assumed horizontal) floor in the area below the targets. Check that the reported height varies by no more than about 5 mm from place to place; this confirms that the XY plane is horizontal and that the Z-axis is vertical. Ignore, for the time being, whether the reported height is actually correct.

If there appears to be a consistent ‘slope’ in one direction, suspect that one or more of the three ‘reference’ targets has an incorrect Z-value. The *free-d*™ software utility includes a ‘levelling’ facility to help correct this error automatically.

7.3 Scale

With the studio camera mounted on a pedestal, and with the pan and tilt locked, move the camera a known distance across the studio floor. Ensure that the orientation of the camera does not change as it is being moved (monitor the returned pan value if in doubt). Compare the distance travelled with that reported by the *free-d*™ system.

If the reported distance and the actual distance differ by more than about 1 part in 500 (10 mm in 5 metres) suspect that one or both of the first two ‘reference’ targets has an incorrect X- and/or Y-value. Correct the fault before proceeding.

7.4 Height and camera Z-offset

With the studio camera mounted on a pedestal, and with the tilt locked at zero, measure the actual camera height above the studio floor (to the appropriate reference point, which is usually the optical axis of the studio camera’s lens). Compare the measured height with that reported by the *free-d*™ system.

If the reported height and the actual height differ by more than about 10 mm suspect either that the three ‘reference’ targets have incorrect Z-values, or that the camera’s Z-offset value is incorrect. The Z-offset value must be measured from the white spot on the side of the upward-looking camera (below the *free-d*™ logo) to the reference point on the studio camera. If the *free-d*™ camera is above the reference point the offset should be negative.

7.5 Camera X-offset

With the studio camera mounted on a locked pedestal or tripod, and with the tilt locked at zero, pan the camera so that the reported pan angle is zero (the camera is then looking along the positive Y-axis). Note the X-position reported by the *free-d*™ system. Now rotate the pan by 180 degrees, so that the camera is looking along the negative Y-axis. The reported X-position should be no more than 5mm different from that previously measured.

If the X-position changes significantly when the pan is changed from 0º to 180º, either the optical axis is not directly above the pan axis of the camera head (in which case this test is not useful) or the X-offset value is incorrect.

The subsequent tests require *free-d*™ to be connected to a virtual-set system, with the ability to view a composite picture consisting of the output from the studio camera keyed over a virtual background.

7.6 CCD centering

Position a real object and a virtual object so they can both be seen in the centre of the composite picture, with the objects chosen so that their relative horizontal and vertical positions can be easily determined. Zoom the studio camera lens fully in and out whilst observing the relative positions of the objects in the centre of the field of view (ignore the rest of the image). Ensure there is no vertical or horizontal shift (slippage) between the real and virtual objects as the zoom is changed.

If there is any shift as the zoom is changed the *CCD centering* needs to be altered; this is usually an adjustment within the virtual-set system. Note that a video timing error (ie, the camera video and the background video not being co-timed at the input to the keyer) can result in a similar symptom.

7.7 Video delay

There is 40ms in 625 or 33ms in 525 (2 fields) delay associated with *free-d*™ tracking system. This means that the real camera output must be delayed by this amount (plus delays associated with the virtual set system) before being combined with the virtual image in the chromakeyer. Please note that in poll-mode (VR system triggered) the delay is 50ms regardless of video format. Only when genlocked with an appropriate studio reference will the delay be reduced to 1 frame (2 fields).

Perform some small, sudden, pan movements and note whether the real and virtual parts of the image move at the same time (ignore, for the moment, whether they move by the same *amount*).

If the real part of the image *leads* the virtual part of the image, more delay in the camera output is needed. If the real part *lags* the virtual part, less delay in the camera output is needed. Note that it is usually only possible to achieve adjustments in steps of one video field (20 ms) or frame (40 ms). To equalise the delay to a closer tolerance, a variable software 'data delay' must be provided by the virtual set system.

7.8 Horizontal view angle

With the lens at its fully telephoto setting, pan the camera from side to side whilst observing the relative positions of a *distant* real object and a *distant* virtual object (Ideally the objects should be at the same distance from the camera).

If the real and virtual objects cross the field-of-view at different rates, the view-angle of the real lens and the view-angle of the virtual lens are different. If the virtual object crosses the field-of-view *faster* than the real object, the view angle of the virtual lens is smaller than that of the real lens. If the virtual object crosses the field-of-view *slower* than the real object, the view angle of the virtual lens is larger than that of the real lens. This may require alteration to a studio lens calibration file, adjustment of the zoom and/or focus sensors or the resetting of a reference point (eg, an end-stop).

Repeat the test with different settings of zoom and focus. If the view angles match at some settings but not at others, the studio lens calibration may need to be corrected. Note that at the wide-angle end of the zoom range lens distortion may be significant, in which case it may not be possible to make the real and virtual objects track accurately over the full width of the image. Note also that, unless the objects are *infinitely distant*, a Y-offset error or a nodal-shift error can result in a similar symptom.

7.9 Vertical view angle and aspect ratio

Repeat the previous test, but this time *tilting* the camera rather than *panning* it. The registration between the real and virtual images should be just as good as it was when the camera was panned.

If the performance is worse when tilting than when panning, suspect that either the studio camera or the virtual set system is selected to the wrong aspect ratio.

7.10 Nodal shift and camera Y-offset

Position a real object and a virtual object (ideally something like a thin vertical pole) as close to the camera as you can whilst being able to focus on it with the lens at its fully wide setting and with a tilt of zero. Ensure that the real and virtual objects are co-sited by observing them from two different directions, 90 degrees apart, and moving one or both as necessary (pan the camera so that the objects are in the centre of the image).

Pan the camera from side to side whilst observing the relative positions of the real and virtual objects. If the real and virtual objects cross the field-of-view at different rates (and having already ascertained in the previous test that the lens angles are the same) the real and virtual viewpoints must not be coincident. If the virtual object crosses the field-of-view *faster* than the real object, the viewpoint of the virtual camera is nearer to the object than the viewpoint of the real camera. If the virtual object crosses the field-of-view *slower* than the real object, the viewpoint of the virtual camera is further away from the object than the viewpoint of the real camera. Check that the Y-offset between the *free-d*™ camera and the reference point on the studio lens has been entered correctly; if the offset is correct the problem is probably one of *nodal shift*.

Repeat the test with different settings of zoom and focus. If the view angles match at some settings but not at others, a *nodal shift* error is probably responsible. This may require alteration to a studio lens calibration file.

Because a large error in the offset values or nodal shift can affect the apparent view angle at all distances, it may be necessary to repeat the Horizontal View Angle section above.

7.11 Pan adjustment

Initially ensure that the virtual and real objects used for the previous test are aligned as seen in the image. Check that the objects are still co-sited by viewing them from two different directions, 90 degrees apart; if necessary move one of the objects to achieve this. Now move the camera to view the objects from a *diametrically opposite* direction (ie, such as the camera's pan angle is 180 degrees from what it was before).

If the objects are no longer aligned horizontally, this indicates that *free-d*™ camera is rotated from its correct orientation about the vertical (pan) axis. To correct this, loosen the camera's mounting screws and rotate it around the vertical axis so as to *halve* the positional error. Now reposition either the real or the virtual object so that they are coincident as seen in the image. Once again view the objects from the opposite side to see if they remain aligned, and if not repeat the adjustment. Once the alignment is correct fully tighten the mounting screws: note that this adjustment is very critical!

7.12 Tilt adjustment

Position a real object and a virtual object (ideally something like a thin horizontal bar) so that their vertical alignment can be judged. View the objects from as short a distance as possible, with the tilt set at zero, and adjust the vertical position of the real or virtual object so that they align. Now *track* the camera backwards, and note whether there is any vertical shift (slippage) between the objects as the camera-object distance increases.

If a significant degree of shift is observed, the *free-d*™ camera needs to be tilted forward or backward (ie, around the X-axis). This can be achieved by rotating the 'wedge rings' that form part of the base plate of the camera, although the tilt and roll cannot be adjusted independently by this means.

7.13 Roll adjustment

Position a tall thin vertical real object and a similar virtual object so that they line up (zoom out so that their entire length can be seen). If necessary adjust one of the objects until they appear to be parallel. Now view the objects from a *diametrically opposite* direction (ie, such as the camera's pan angle is 180 degrees from what it was before).

If the objects no longer appear to be parallel, the *free-d*™ camera needs to be rolled clockwise or anticlockwise (ie, around the Y-axis). This can be achieved by rotating the 'wedge rings' which form part of the base plate of the camera, although the tilt and roll cannot be adjusted independently by this means.

Appendix A, *free-d*™ communications protocol v1.0

A.1 General

Communications with the *free-d*™ unit use RS422/RS485 serial data as follows:

Baud rate:	38.4 kbaud
Data bits:	8 (LSB first)
Parity:	Odd
Stop bits:	1
Total bits:	11

Data is transferred in messages. Each message consists of:

Message type
Camera ID number
Data (depending on message type)
Checksum

Multi-byte data values are sent most-significant-byte first.

The checksum is calculated by subtracting (modulo 256) each byte of the message, including the message type, from 40 (hex).

The Camera ID number identifies the camera concerned. If the Camera ID of a message received by the *free-d*™ unit does not match that of the camera to which the unit is connected, the message is ignored. However, if the Camera ID is set to FF (hex) no comparison is made and the message is always recognised. Messages transmitted by the *free-d*™ unit carry the ID number of the camera to which it is connected.

A.2 Protocols

There are two modes of operation, stream mode and polled mode. In stream mode, the *free-d*™ unit will send position updates continuously at an approximate rate of 30 per second. In polled mode, the *free-d*™ unit will send a message only when specifically requested - a maximum rate of 100 polls per second is allowed. Switching between the two modes is possible using a command message.

The *free-d*™ unit initialises itself to a ‘Radamec-compatible’ stream mode, in which it transmits messages with the same format as would be returned by a robotic pedestal. Since Radamec-format messages have no provision for a camera ‘roll’ value, in this mode the camera must be mounted on a tripod or other suitable platform.

A.3 Message structures

A.3.1 Type D0 - poll / command

The D0 message is used to poll the Free-d unit for data, or to send a command to the *free-d*™ unit.

The message contains 4 bytes as follows:

<D0>	Message type
<CA>	Camera ID
<CD>	Command
<CK>	Checksum

Commands presently defined are:

00	Stop stream mode
01	Start stream mode
02	Stop freeze mode
03	Start freeze mode
D1	Poll for position update (and stop stream mode)
D2	Request system status
D3	Request system parameters
D4	Request first target data
D5	Request next target data
D6	Request first image point
D7	Request next image point
D8	Request next EEPROM data
DA	Request camera calibration values
DB	Request diagnostic mode

A.3.2 Type D1 - camera position/orientation data

The D1 message is used for transferring the camera position and orientation data from the *free-d*™ unit.

The message contains 29 bytes as follows:

<D1>	Message type
<CA>	Camera ID
<PH><PM><PL>	Camera Pan Angle
<TH><TM><TL>	Camera Tilt Angle
<RH><RM><RL>	Camera Roll Angle
<XH><XM><XL>	Camera X-Position
<YH><YM><YL>	Camera Y-Position
<HH><HM><HL>	Camera Height (Z-Position)
<ZH><ZM><ZL>	Camera Zoom
<FH><FM><FL>	Camera Focus
<SH><SL>	Spare / User Defined (16 bits)
<CK>	Checksum

See Appendix B for details of the content of this message.

A.3.3 Type D2 - system status

The D2 message is used for transferring the system status from the *free-d*™ unit.

The message contains 16 bytes as follows:

<D2>	Message type
<CA>	Camera ID
<SW>	Switch settings
<LD>	LED indications
<FS>	System status
<CV>	CPU firmware version number
<PV>	PLD firmware version number
<DV>	DSP software version number
<DS>	DSP status
<MR>	Number of targets seen (i.e. detected by hardware)
<MC>	Number of targets identified (i.e. bar-codes read)
<NP>	Number of targets used (identified and in database)
<EH><EM><EL>	RMS error
<CK>	Checksum

Bits in the 'switch settings' byte are as follows:

Bits 0-3:	Setting of the hex switch S5 (inverted)
Bit 4:	0 = S2 left (decrease value / scroll left)
Bit 5:	0 = S2 right (increase value / scroll right)
Bit 6:	0 = S4 closed (save settings)
Bit 7:	0 = S3 left (results mode), 1 = S3 right (entry mode)

Bits in the 'LED indications' byte are as follows:

Bit 0:	1 = video input present
Bit 1:	1 = video input OK
Bit 2:	1 = serial data input present
Bit 3:	1 = data 'freeze' mode, 0 = normal
Bit 4:	1 = too few targets
Bit 5:	1 = RMS error high
Bit 6:	1 = DSP alert (see DSP status)
Bit 7:	1 = fault (see system status)

Note that only one 'video input' LED (D3) is present in the hardware, which lights when both Bit 0 and Bit 1 of the 'LED indications' byte are set.

The version numbers should be interpreted as BCD, with an implied decimal point between the two digits; eg, 12 (hexadecimal) refers to version 1.2.

The RMS error is expressed in pixels as a 24-bit positive number, where the most-significant bit (bit 23) is always zero, the next 8 bits (bits 22 to 15) are the integer part and the remaining bits (bits 14 to 0) are the fractional part; alternatively, this may be thought of as an unsigned integer value in units of 1/32768 pixels. The range of values is from zero to nearly 256.0 pixels (7FFFFF hex).

The 'DSP alert' bit is set whenever the DSP status is negative (bit 7 set).

The 'fault' bit is set whenever the system status byte is non-zero.

The system status is an 8-bit number which can take one of the following values:

0	System normal (no detected errors).
1	A processor reset occurred. This code is only present transitorily.
2	Serial communications error. This is most likely to be caused by a message being sent to the Free-d unit before the reply to the previous message has been received.
3	Vertical blanking failure. This may indicate a hardware fault, or a problem with the digital video input.
4	Xilinx failure. The programmable logic devices have not initialised correctly; if persistent, this indicates a hardware fault.
5	I2C bus failure. Communication between the CPU and peripheral devices has failed, indicating a probable hardware fault.
6	EEPROM failure. An attempt to save the parameters to non-volatile memory U3 has failed, indicating a probable hardware fault.
7	DSP failure (1). The DSP failed to acknowledge a command; if persistent, this indicates a hardware fault.
8	DSP failure (2). The DSP failed to accept data; if persistent, this indicates a hardware fault.
9	DSP failure (3). The DSP failed to provide data; if persistent, this indicates a hardware fault.
10	DSP failure (4). The DSP is flagging an exception error; if persistent, this indicates a hardware or software fault.
91	I2C communication failure: No Reply.
93	I2C communication failure: Bus Error.
94	I2C communication failure: ACK Error.
95	I2C communication failure: Undefined State.
96	I2C communication failure: Overflow.

The ‘I2C communication failure’ codes result from a problem with communication between the processor and the I2C peripherals U3 and U17, most likely indicating a hardware fault.

The DSP status is a signed 8-bit number which when negative indicates an error condition as follows:

-1 Too few valid targets visible to compute camera position.
-2 Iteration failed to converge.
-3 A DSP reset occurred.
-4 Internal DSP error.

A zero or positive value of DSP status indicates the number of iterations which were required to compute the camera's position.

A.3.4 Type D3 - control parameters

The D3 message is used for transferring the control parameters. It may be sent to the *free-d*™ unit in order to set their values, or requested from the *free-d*™ unit in order to interrogate the current values. Operation of switch S4 saves the current values to EEPROM, which become the default values following a subsequent processor reset.

The message contains 13 bytes as follows:

<D3>	Message type
<CA>	Camera ID
<SN>	Studio ID
<SM>	Smoothing value
<HI>	Maximum asymmetry
<HO>	Half box width
<BT>	Black video threshold
<WT>	White video threshold
<BC>	Black video clip level
<WC>	White video clip level
<MB>	Maximum number of >black pixels between boxes
<MW>	Minimum number of >white pixels in inner box
<CK>	Checksum

The ‘studio ID’ is in the range 0 to 255 and determines which database of target positions (stored in the on-board EEPROM) is used.

The ‘smoothing value’ is in the range 0 to 255, corresponding to settings of smoothing between 0.000 and 0.996.

The ‘maximum asymmetry’ is in the range 0 to 255, in units of 1/128 pixels. This sets a limit on the difference between the centre position of a target as measured by the hardware and its position as estimated as the mid-point between opposite edges.

The ‘half box width’ determines the size of the outer box used in target detection. The maximum value is 41 pixels: if a larger value is set the unit will not operate correctly; the box height is calculated to ensure the box is square. A value of zero signifies ‘automatic’: the *free-d*™ unit sets the box size according to the apparent size of the targets in the image.

The ‘black video clip level’ and ‘white video clip level’ determine the clipping, which is applied before the target's position is measured. Too little clipping can make the position measurement over-sensitive to level variation, such as might be caused by uneven illumination. Too much clipping, however, can cause excessive aliasing, which can impair the measurement accuracy.

The ‘maximum number of black pixels’ and ‘minimum number of white pixels’ values are used in conjunction with the ‘black video threshold’ and ‘white video threshold’ to control the target detection process. A target is recognised if there are at least the specified minimum number f pixels above the ‘white’ threshold within the inner box, and at most the specified maximum number of pixels above the ‘black’ threshold between the inner and outer boxes.

The *free-d*™ unit acknowledges receipt of a D3 message by replying with a D3 message containing the new data.

A.3.5 Type D4 & D5 - target data

The D4 and D5 messages are used for transferring target data from the *free-d*™ unit. Each message contains data about a single target: requesting message D4 causes data for target zero to be transmitted and requesting message D5 causes data for the next target in sequence to be transmitted. After data for the last target has been sent, the next message will contain data for the first target, with a message type of D4 (whether the request was for D4 or D5).

The messages contain 18 bytes as follows:

<D4> or <D5>	Message type
<CA>	Camera ID
<SN>	Studio ID
<MH><ML>	Target Number
<XH><XM><XL>	Target X-Position
<YH><YM><YL>	Target Y-Position
<HH><HM><HL>	Target Height (Z-Position)
<FH><FM><FL>	Target Flags
<CK>	Checksum

The X-Position, Y-Position and Height are sent in the same format as the camera position in message D1 (see Appendix B).

The MSB of Target Flags (bit 7 of FH) is set for a valid target and cleared for an invalid target. If the target is flagged as invalid its position data should be ignored.

A.3.6 Type D6 & D7 - image data

The D6 and D7 messages are used for transferring image data from the *free-d*™ unit. Each message contains data about a single target: requesting message D6 causes data for the first target in the image to be transmitted and requesting message D7 causes data for the next target in the image to be transmitted. After data for the last target has been sent, the next message will contain data for the first target, with a message type of D6 (whether the request was for D6 or D7).

The messages contain 18 bytes as follows:

<D6> or <D7>	Message type
<CA>	Camera ID
<MI>	Target Index (zero for message D6)
<MH><ML>	Target Number
<XH><XM><XL>	X-Position in image
<YH><YM><YL>	Y-Position in image
<AH><AM><AL>	Error in X-Position
<BH><BM><BL>	Error in Y-Position
<CK>	Checksum

The X-Position and Y-Position are positive values in units of 1/256 pixels (i.e. XH, XM is the integer part of the X-Position in pixels and XL is the fractional part).

The Error values are signed and in units which depend on the lens calibration. To obtain values in pixels the X-Error must be divided by X-Scale (see message DA) and multiplied by 512. Similarly the Y-Error must be divided by Y-Scale and multiplied by 512.

A.3.7 Type D8 - EEPROM data

The D8 message is used for transferring EEPROM data from or to the *free-d*™ unit. If a D8 message is sent to the *free-d*™ unit the EEPROM is programmed with the data supplied, and the *free-d*™ unit replies with a D8 message containing the new data.

The message contains 21 bytes as follows:

<D8>	Message type
<CA>	Camera ID

<EH><EL>	EEPROM Address
<D0>....<DF>	16 bytes of EEPROM data
<CK>	Checksum

The EEPROM can only be programmed or read 16-bytes at a time. The EEPROM Address within the message corresponds to the address of the first byte of data transferred.

A.3.8 Type D9 - request EEPROM data

The D9 message is used to request the transfer of EEPROM data from the *free-d*™ unit. The *free-d*™ unit replies with a D8 message containing 16 bytes of EEPROM data.

The message contains 5 bytes as follows:

<D9>	Message type
<CA>	Camera ID
<EH><EL>	EEPROM address
<CK>	Checksum

The EEPROM Address determines the address of the first data byte to be transferred.

A.3.9 Type DA - camera calibration data

The DA message is used for transferring Camera Calibration data from the *free-d*™ unit. The data corresponds to the camera currently in use. If a valid camera is not connected to the *free-d*™ unit, or if the camera has only recently been connected, the data is invalid.

The message contains 30 bytes as follows:

<DA>	Message type
<CA>	Camera ID
<CH><CM><CL>	Lens X-Centre
<DH><DM><DL>	Lens Y-Centre
<SH><SM><SL>	Lens X-Scale
<TH><TM><TL>	Lens Y-Scale
<AH><AM><AL>	Lens Distortion A (radial, square term)
<BH><BM><BL>	Lens Distortion B (radial, fourth power)
<XH><XM><XL>	X-Offset from auxiliary camera to studio camera
<YH><YM><YL>	Y-Offset from auxiliary camera to studio camera
<ZH><ZM><ZL>	Z-Offset from auxiliary camera to studio camera
<CK>	Checksum

A.3.10 Type DB - diagnostic mode

The DB message is used to switch the *free-d*™ unit into a diagnostic mode, or to return the diagnostic mode currently set.

The message contains 4 bytes as follows:

<DB>	Message type
<CA>	Camera ID
<DM>	Diagnostic mode
<CK>	Checksum

Only the two most-significant bits of Diagnostic Mode are defined. The possible modes are as follows:

00	Normal operation
40	Set video data to 0x55
80	Set video data to 0xAA
C0	Set video data to test pattern

The *free-d*™ unit acknowledges receipt of a DB message by replying with a DB message containing the new mode.

A.3.11 Type A4 - poll / command (Radamec compatibility mode)

The A4 message is used to poll the Free-d unit for data, or to send a command to the *free-d*™ unit, in a way compatible with the Vinten Radamec RP2VR robotic pedestal.

The message contains 4 bytes as follows:

<A4>	Message type
<CA>	Camera ID
<CD>	Command
<CK>	Checksum

Commands presently defined are:

00	Stop Radamec-compatible stream mode
01	Start Radamec-compatible stream mode
02	Request camera ID
FF	Poll for Radamec-compatible position update

For commands 00 and 01 the *free-d*™ unit acts on the message but does not reply.

In the case of command 02 (request camera ID) the <CA> byte in the message should be set to FF. The *free-d*™ unit replies with an A4 message having the <CA> byte set to the current camera ID and the <CD> byte set to 02.

For command FF (poll) the *free-d*™ unit replies with an A2 message.

A.3.12 Type A2 - camera position/orientation data (Radamec mode)

The A2 message is used for transferring the camera position and orientation data from the Free-d unit in a form compatible with Vinten Radamec robotic pedestals. Note that there is no provision to send a 'roll' value, so the camera must be mounted on a tripod or pedestal.

The message contains 30 bytes as follows:

<A2>	Message type
<CA>	Camera ID
<PH><PM><PL>	Camera Pan Angle
<TH><TM><TL>	Camera Tilt Angle
<ZH><ZM><ZL>	Camera Zoom
<FH><FM><FL>	Camera Focus
<HH><HM><HL>	Camera Height (Z-Position)
<XFH><XFL>	Camera X-Position (fraction)
<XIH><XIL>	Camera X-Position (integer)
<YFH><YFL>	Camera Y-Position (fraction)
<YIH><YIL>	Camera Y-Position (integer)
<00><00>	Pedestal Orientation (set to zero)
<SH><SL>	Spare / User Defined (16 bits)
<CK>	Checksum

The Pan Angle is expressed as a 24-bit integer in units of 1/900 degrees, where zero is represented by 080000 hex. The range of values is from -180.0 degrees (058730 hex) to +180.0 degrees (0A78D0 hex).

The Tilt Angle is expressed as a 24-bit integer in units of 1/900 degrees, where zero is represented by 080000 hex. The range of values is from -90.0 degrees (06C398 hex) to +90.0 degrees (093C68 hex).

The Camera Zoom is expressed as a 24-bit positive unsigned number in arbitrary units related to the rotation of the 'zoom ring' on the camera lens. It will be necessary for the host system to convert this to a true zoom value based on the type and particular sample of lens and camera in use.

The Camera Focus is expressed as a 24-bit positive unsigned number in arbitrary units related to the rotation of the 'focus ring' on the camera lens. It will be necessary for the host system to convert this to a true focus value based on the type and particular sample of lens and camera in use.

The Height is expressed as a 24-bit integer in units of 1/82.2 mm. The range of values is from -102,051.2 mm (800000 hex) to +102,051.2 mm (7FFFFF hex).

The X-Position and Y-Position are expressed in units of millimetres as a 16-bit integer part and a 16-bit fractional part. The range of values is from -32,768 mm (integer part 8000 hex, fractional part 0000hex) to almost +32,768 mm (integer part 7FFF hex, fractional part FC00hex).

Note that, unlike a Vinten Radamec robotic pedestal and camera head, it is not possible to pre-load the encoder positions by transmitting an A2 message to the *free-d*™ unit.

Appendix B, Camera positioning parameters

The following sections describe the parameters used to convey the position, orientation etc. of the studio camera.

B.1 Definition of axes

A set of orthogonal right-handed axes (X, Y and Z) is used, fixed with respect to the reference frame of the studio. The X and Y axes lie in the horizontal plane, and the Z axis is vertical. The positive direction of the Z-axis is upwards.

B.2 Camera pan angle

The Camera Pan Angle is defined as the angle between the Y-axis and the projection of the optical axis of the camera onto the horizontal (XY) plane. A zero value corresponds to the camera looking in the positive Y direction and a positive value indicates a pan to the right (ie, the camera rotates clockwise when viewed from above).

The value is expressed in degrees as a 24-bit twos-complement signed number, where the most-significant bit (bit 23) is the sign bit, the next 8 bits (bits 22 to 15) are the integer part and the remaining bits (bits 14 to 0) are the fractional part; alternatively, this may be thought of as a signed integer value in units of 1/32768 degree. The range of values is from -180.0 degrees (A60000 hex) to +180.0 degrees (5A0000 hex).

B.3 Camera tilt angle

The Camera Tilt Angle is defined as the angle between the optical axis of the camera and the horizontal (XY) plane. A positive value indicates an upwards tilt. If the pan and tilt angles are both zero, the camera is looking in the direction of the positive Y axis.

The value is expressed in degrees as a 24-bit twos-complement signed number, where the most-significant bit (bit 23) is the sign bit, the next 8 bits (bits 22 to 15) are the integer part and the remaining bits (bits 14 to 0) are the fractional part; alternatively, this may be thought of as a signed integer value in units of 1/32768 degree. The range of values is from -90.0 degrees (D30000 hex) to +90.0 degrees (2D0000 hex).

B.4 Camera roll angle

The Camera Roll Angle is defined as the angle of rotation of the camera about its optical axis. A roll angle of zero corresponds to a 'scan line' of the camera sensor (ie, a horizontal in the image) being parallel to the horizontal (XY) plane. A positive value indicates a clockwise roll, when viewed from behind the camera.

The value is expressed in degrees as a 24-bit twos-complement signed number, where the most-significant bit (bit 23) is the sign bit, the next 8 bits (bits 22 to 15) are the integer part and the remaining bits (bits 14 to 0) are the fractional part; alternatively, this may be thought of as a signed integer value in units of 1/32768 degree. The range of values is from -180.0 degrees (A60000 hex) to +180.0 degrees (5A0000 hex).

B.5 Camera x-position

The Camera X-Position is defined as the horizontal displacement of the camera from its reference position in the direction of the X-axis.

The value is expressed in millimetres as a 24-bit twos-complement signed number, where the most-significant bit (bit 23) is the sign bit, the next 17 bits (bits 22 to 6) are the integer part and the remaining bits (bits 5 to 0) are the fractional part; alternatively, this may be thought of as a signed integer value in units of 1/64 mm. The range of values is from -131,072.0 mm (800000 hex) to nearly +131,072.0 mm
(7FFFFF hex).

B.6 Camera y-position

The Camera Y-Position is defined as the horizontal displacement of the camera from its reference position in the direction of the Y-axis.

The value is expressed in millimetres as a 24-bit twos-complement signed number, where the most-significant bit (bit 23) is the sign bit, the next 17 bits (bits 22 to 6) are the integer part and the remaining bits (bits 5 to 0) are the fractional part; alternatively, this may be thought of as a signed integer value in units of 1/64 mm. The range of values is from -131,072.0 mm (800000 hex) to nearly +131,072.0 mm
(7FFFFF hex).

B.7 Camera height (z-position)

The Camera Height is defined as the vertical displacement of the camera from its reference position. A positive value indicates an upwards displacement.

The value is expressed in millimetres as a 24-bit twos-complement signed number, where the most-significant bit (bit 23) is the sign bit, the next 17 bits (bits 22 to 6) are the integer part and the remaining bits (bits 5 to 0) are the fractional part; alternatively, this may be thought of as a signed integer value in units of 1/64 mm. The range of values is from -131,072.0 mm (800000 hex) to nearly +131,072.0 mm (7FFFFF hex).

B.8 Camera zoom

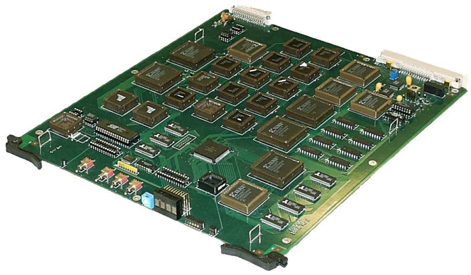
The Camera Zoom is defined as the vertical angle of view of the camera; ie, the vertical angle subtended at the camera lens by the top and bottom edges of the active picture.

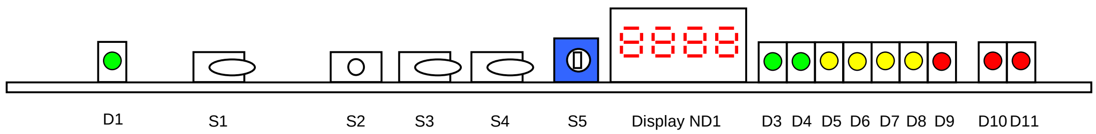
The value is expressed as a 24-bit positive unsigned number in arbitrary units related to the rotation of the ‘zoom ring’ on the camera lens. It will be necessary for the host system to convert this to a true zoom value based on the type and particular sample of lens and camera in use.

B.9 Camera focus

The Camera Focus is defined as the distance between the camera lens and an object at which the object will be in sharp focus. The value is expressed as a 24-bit positive unsigned number in arbitrary units related to the rotation of the ‘focus ring’ on the camera lens. It will be necessary for the host system to convert this to a true focus value based on the type and particular sample of lens and camera in use.

Appendix C, *free-d*™ Processor card settings and warnings





Switch Number	Function
S1	Reset
S2	left position: scroll display left right position: scroll display right
S3	left position: display/change control parameters right position: display calculated results
S4	STORE/SAVE settings
S5	Display select

S5 setting	S3 left	S3 right
0	studio name	Camera name
1	smoothing value	No. of targets used
2	max asymmetry	Overall RMS error
3	box size	cam X position (mm)
4	black threshold	cam Y position (mm)
5	white threshold	cam height (mm)
6	black clip value	cam pan angle (deg)
7	white clip value	cam tilt angle (deg)
8	max non-black	cam roll angle (deg)
9	min white	cam data
A	target to interrogate	Image x-centre
B	image X position	Image Y-centre
C	image Y position	pixel x-scaling
D	world X position	pixel X scaling
E	world Y position	lens distortion A
F	world height	lens distortion B

LED indications	
d1-green	Off = no power, on= CPU O.K, flashing= CPU resetting (fault)
d3-green	On = video input present and locked
d4-green	On = serial data input present
d5-yellow	On = data freeze mode
d6-yellow	On = too few targets
d7-yellow	On = RMS error high
d8-yellow	On = DSP alert
d9-red	On = fault (code shown on alphanumeric display)
d10-red	On = Xilinx booting error or failed
d11-red	On = DSP booting error or failed

ND1	Alphanumeric Display Error Codes
E1	A processor reset has occurred (this code is only transitory).
E2	Serial communications error.
E3	Vertical blanking failure. This maybe a hardware fault or a problem with the digital Input.
E4	Xilinx failure. The programmable logic devices have not initialised correctly.
E5	I2C bus failure. Communication between the CPU and peripheral. Hardware fault.
E6	Eprom failure, U3.
E7	DSP has failed to acknowledge a command. If persistent this indicates a hardware.
E8	DSP has failed to accept data. If persistent this indicates a hardware fault.
E9	DSP has failed to provide data. If persistent this indicates a hardware fault.
E10	DSP is flagging an exception error. If persistent this indicates a h/w or s/w fault.
E91	I2C communication failure. No reply
E93	I2C communication failure. Bus error
E94	I2C communication failure. ACK error
E95	I2C communication failure. Undefined state
E96	I2C communication failure. Overflow
F000	The Xilinx FPGAs have not configured correctly. Suspect a hardware fault or incorrectly programmed U33
F1xx	DSP fault: F100: Failed to boot, F110: memory self test failed or no video i/p present
F118	Software error
F2xx	Video bus VO failed
F3xx	Video bus V4 failed
F4xx	Filter bus RAF1 failed
F5xx	Filter bus RAF2 failed
F6xx	Filter bus RAF3 failed
F7xx	Filter bus SYM1 failed
F8xx	Filter bus SYM2 failed
F9xx	An attempt to select page 2 of video RAM resulted in error code xx (hex)
Faxx	Even video RAM failed.
FBxx	Odd video RAM failed.
FCxx	Dual-port RAM (U10) failed.
FDxx	Dual-port RAM (U4) failed.
FExx	Dual-port RAM (U10) failed.
FFxx	Dual-port RAM (U4) failed.

A transitory error code that does not re-appear on a subsequent reset should not be considered to indicate a fault condition.

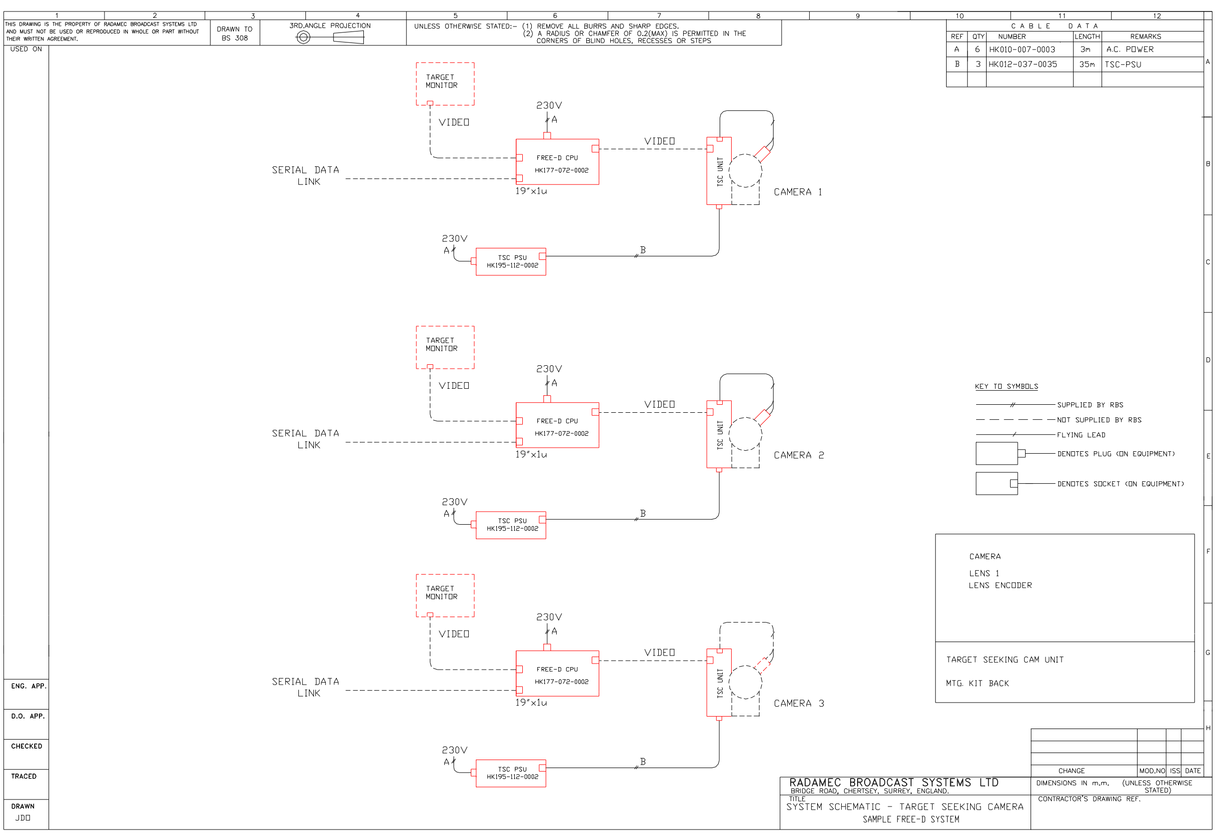
Appendix D, *free-d*™ Target seeking camera ID settings

Switch S101	Camera ID Number	Switch S101	Camera ID Number
E	1 (10 in lom1)	7	9 (90 in lom1)
D	2 (20 in lom1)	6	10 (A0 in lom1)
C	3 (30 in lom1)	5	11 (B0 in lom1)
B	4 (40 in lom1)	4	12 (C0 in lom1)
A	5 (50 in lom1)	3	13 (D0 in lom1)
0	6 (60 in lom1)	2	14 (E0 in lom1)
9	7 (70 in lom1)	1	15 (F0 in lom1)
8	8 (80 in lom1)	F	16 (00 in lom1)

Appendix E, *free-d*™ Target seeking camera exposure settings

Switch S102	Exposure time	Remarks
0 - D	1/2,000 sec (7.5 tv lines)	Max exposure, max depth of field
E	1/4,000 sec (3 tv lines)	
F	1/10,000 sec (1.5 tv lines)	Suitable for fast camera moves

Appendix F, Typical system schematic and part numbers



Appendix G, Target array template diagram