MIRA 3D

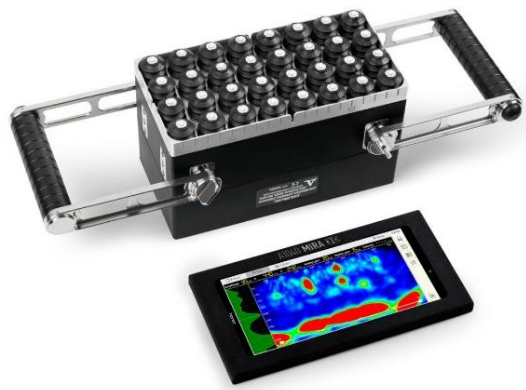
Purpose

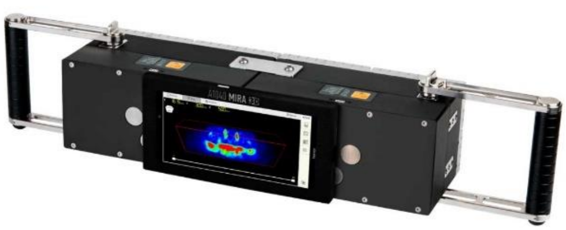
The **MIRA 3D** is the advanced version of the well-known, state-of-the-art, MIRA Ultrasound Tomographer. It creates a three-dimensional representation (tomogram) of internal defects that may be present in a concrete element. **MIRA 3D** is based on the ultrasonic pitch-catch method and uses an antenna composed of an array of active dry point contact (A-DPC) transducers with enhanced penetration depth, which emit shear waves into the concrete and receive them. The 4 by 8 transducer array is under wireless control by a powerful smartphone and the recorded data are analyzed to create a 2-D image of the reflecting interfaces within the cross section below the antenna. A series of 2-D images obtained from the test object can be processed into a complete 3-D reconstruction and displayed on the smartphone's screen. The information can also be transferred to a computer with the **IntroView** imaging software. The software gives additional tools to manipulate the 3-D images for interpretation and reporting of test results.

Furthermore, the best novelty of the **MIRA 3D** is that it also has available an operation mode which uses a technique of data collection known as Full-Matrix-Capture (FMC) where the signal is produced and received by each individual transducer in the antenna array so the pitch-catch, time-of-flight measurements are captured for every possible transmitter-receiver combination in the antenna. Thus, real-time, 3D and cross-sectional visualizations are possible for individual measurements, i.e., at each instrument position (true 3D tomography).

MIRA 3D can be used for the following applications:

- Thickness measurement
- Detection of voids in grouted tendon ducts
- Detection of poor-quality bond in overlays and repairs
- Detection of delaminations
- Detection of voids and honeycombing in concrete members
- Detection of voids behind tunnel linings and below slabs on ground.
- While not intended for that purpose, **MIRA 3D** is also capable of detecting steel reinforcement.

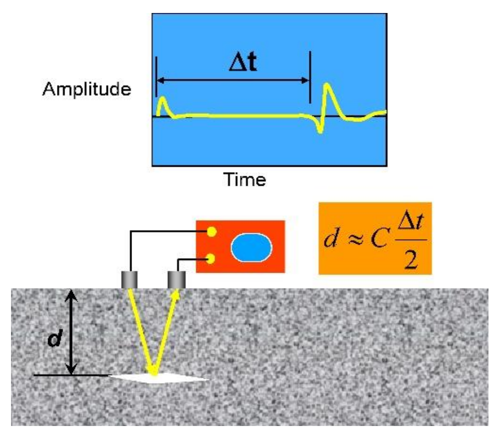




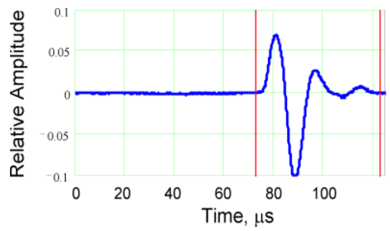
For better and faster scan coverage, the active aperture of the instrument can be extended by attaching and synchronizing a second antenna array. This enlarged version is the **MIRA 3D PRO**.

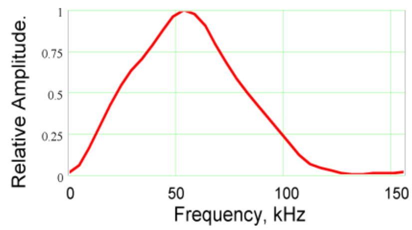
Principle

MIRA 3D is based on the ultrasonic pulse-echo method using transmitting and receiving transducers in a "pitch-catch" configuration as shown on the right. In the pitch-catch method, one transducer sends out a stress-wave pulse and a second transducer receives the reflected pulse. The time from the start of the pulse until the arrival of the echo is measured. If the wave speed ***C*** is known, the depth of the reflecting interface can be calculated as shown (the equation assumes that the two transducers are close to each other).

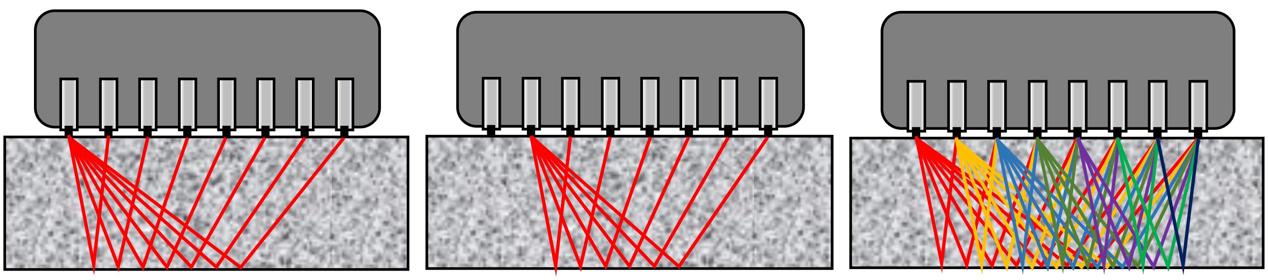


In the **MIRA 3D** system, the antenna is composed of a 4 by 8 array of point transducers and a control unit that operates them. The transducers are heavily damped so that a short duration pulse is created. The plot in blue below shows the typical shape of the received pulse after it has reflected from an air interface. The plot in red to the right shows the amplitude spectrum of the pulse (the nominal center frequency is about 50 kHz but can be varied from 10 to 100 kHz, allowing the user to control both penetration depth and image resolution).

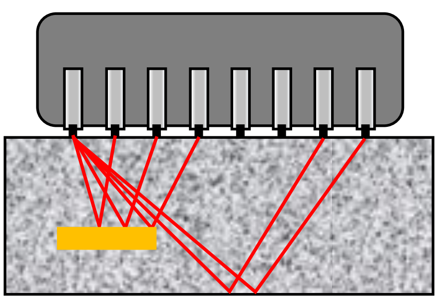




Basically, in the traditional mode of operation, the control unit excites one row of transducers and the other rows of transducers act as receivers. The left side figure below shows the ray paths of the measured transit time of the first row of transducers acting as transmitters and the remaining rows of transducers acting as receivers. Then, as shown in the figure in the center, the next row of transducers is exited and the other rows to the right act as receivers. This process is repeated until each of the rows of transducers has acted as transmitter.



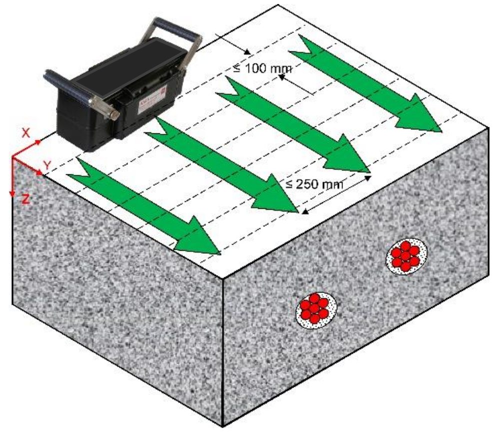
The figure to the right shows the 28 ray paths for the 4 x 8 array that are involved during a measurement at one test location. Data processing and visualization of the B-Scan (2-D image of the cross section below the antenna) are made in real time at each location. The reconstructed image shows the locations of the reflecting interfaces, which could be the opposite side of the member (back wall reflection), reinforcing bars, and most importantly, internal concrete-air interfaces such as voids, cracks, delaminations, etc.



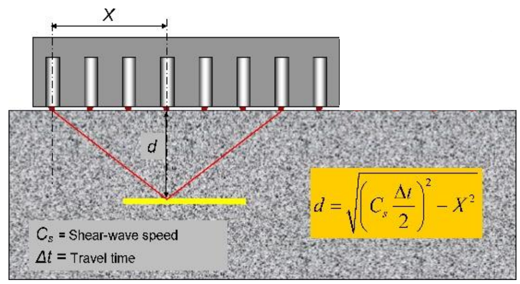
If there is a sufficiently large concrete-air interface, like a defect within the member, a portion of the emitted stress pulse will be intercepted and reflected by the defect instead of traveling all the way to the back wall. As illustrated in the figure to the left, because of the shorter ray paths, reflections from the defect will arrive at the receivers sooner than reflections from the back wall. The instrument uses the arrival times of the reflected pulses to determine the location of the defect within the member.

In the **new MATRIX operation mode** that **MIRA 3D** is also equipped with, the Full-Matrix-Capture (FMC) data collection technique is used together with the processing algorithm known as Total Focusing Method (TFM) to compute the arrival-time data acquired from all directions of the many transducer pairs in the antenna array and directly reconstruct 3D images of the reflecting interfaces within the volume of the object below the antenna at each test position. This "true 3D tomography" system provides greater imaging resolution and precision compared to standard phased array ultrasonic measurements.

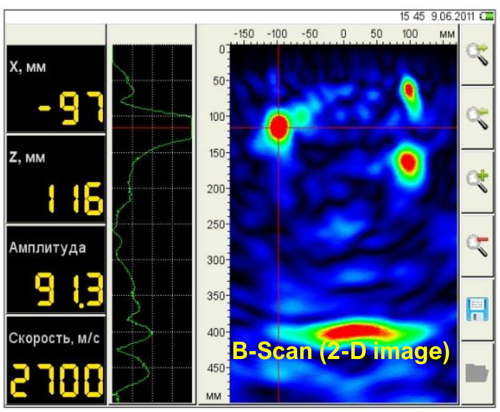
Full-area Scanning and 3D Reconstruction



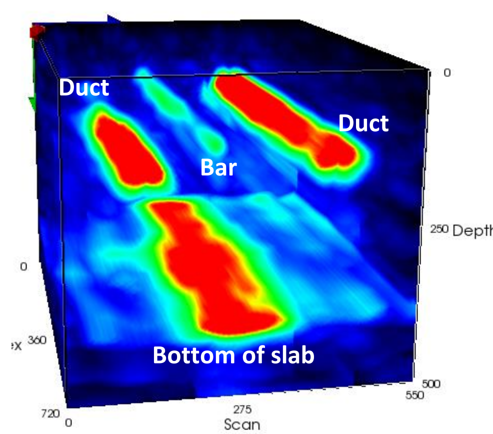
To carry out a detailed inspection of a portion of the member, the user lays out a series of parallel scan lines on the testing surface, which are shown as green arrows in the figure on the right. Another series of lines perpendicular to the scan lines is laid out, which are shown as dashed lines. The antenna is oriented perpendicular to the direction of the scan lines and data are recorded at each "vertical step" along each scan line. After taking data along the first scan line, the operator moves to the beginning of the next scan line. This testing grid is then used during image reconstruction to establish the locations of the reflecting interfaces within the test object under the whole scanned area.



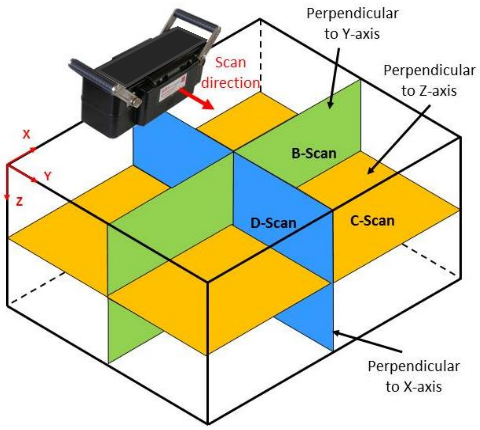
After transit time data are acquired at a test location, the signal processing technique reconstructs the interior of the concrete member at the test location by subdividing the region below the antenna into small discrete elements (analogous to finite elements used for stress analysis). From the pulse arrival times and the known positions of the transmitter-receiver pairs, the depth of the reflecting interface can be established. Because of the inclined ray paths, the depth of the reflector is calculated using the formula for the relationship between the lengths of the sides of a right triangle. In the formula shown in the above figure, C_s is the shear wave speed determined by **MIRA 3D** itself at the start of each measurement or the specific value entered by the user in the setup. Volume elements that correspond to locations of reflecting interfaces are assigned a color to indicate intensity of reflection from those elements (constructive superposition). The end result is, depending on the operating mode chosen, either a 2-D or a 3-D image (for classic linear mode or matrix mode, respectively) representing the locations of reflecting interfaces in the region below the antenna at each position on the grid.

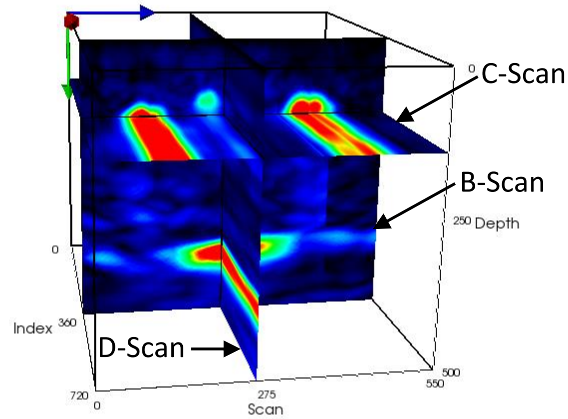


After completion of the measurements over all the points on the testing grid, the individual scans are “stitched” together to create a full 3-D model of the test object that can be visualized directly in the screen of the **MIRA 3D** control unit. Alternatively, the data can also be transferred to a laptop computer that contains the **IntroView** 3-D visualization software. As an example, the figure on the right is the reconstructed 3-D model from a scan of a portion of a slab containing two tendon ducts and a reinforcing bar. The bottom of the slab is indicated.



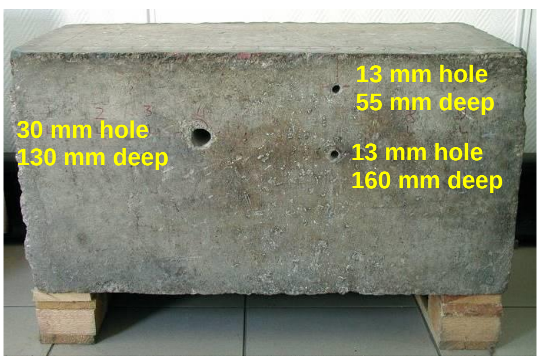
The user can manipulate the 3-D model by rotating it or looking at different orthogonal planes cutting through the model. In left figure below a **C-scan** shows the reflecting interfaces on a plane parallel to the test surface and at different depths (Z-axis); that is, it provides a "plan view" of the reflectors. A **B-scan** provides an "end view" of the reflectors and the **D-scan** provides a side view of the reflectors. The user can look at specific "slices" through the 3-D model by defining the coordinates of any of the three X, Y or Z axes. For example, the right figure below shows three slicing planes through the 3-D model of the slab with the ducts.

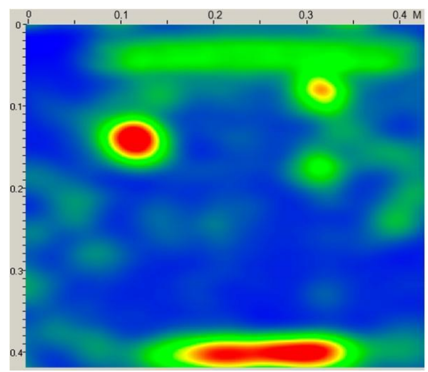




Examples

Plain concrete block with holes: The test object is a 0.8 m x 0.43 m x 0.43 m plain concrete block into which three holes were cast as shown. The scanning was along the top of the block parallel to the direction of the holes. The resulting B-scan image is shown to the right. The three holes are seen clearly and the red band at the bottom represents reflections from the bottom of the block. Because of the inclined ray paths, it is possible to see the deeper 13-mm hole directly below the upper 13-mm hole.





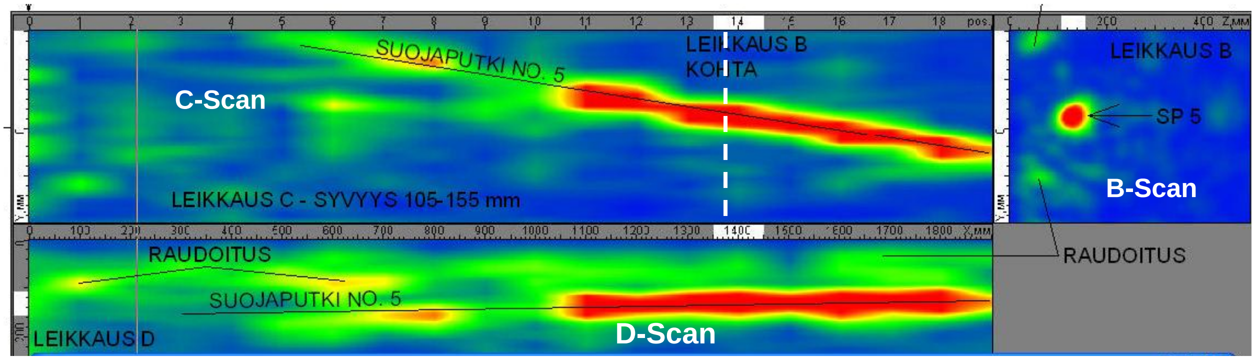
Testing for voids in grouted cable ducts of bridge girders: The instrument was used to evaluate the conditions of grouted post-tensioning ducts near the anchorage zone in the webs of a box-girder bridge. Before testing, the locations of the ducts were marked on the face of the web (center photo below). One of the test records is shown below. The B-scan is at the cross section shown as a dashed


Scanning along web


View of web and drilled core

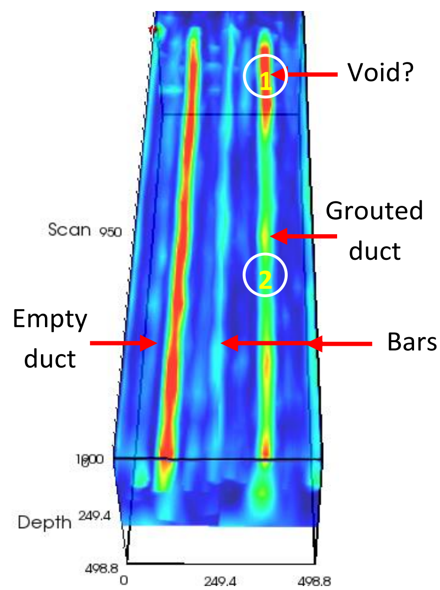

Condition of duct

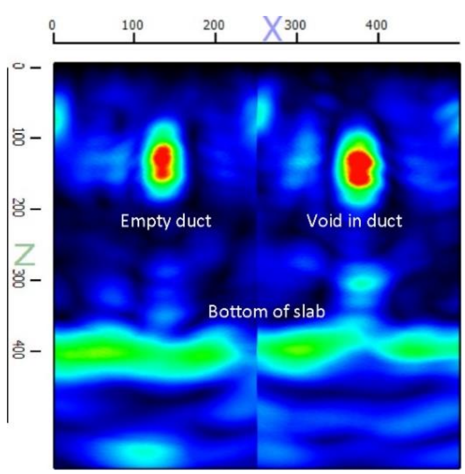
white line in the C-scan. The large amplitude signal in the B-scan at the location of the duct indicated a high probability that the duct was not fully grouted. This was confirmed by drilling a core and carefully removing the duct to reveal bare strands as shown in the photo on the right. (Courtesy of Ramboll Finland Ltd.)



Tendon Ducts in Slab Specimen: A 400-mm thick slab-on-ground was cast at the Germann Instruments' facilities in Copenhagen. The slab contains two 100-mm diameter metal tendon ducts with a cover of 100 mm. One duct is empty and the other contains 10 grouted, 16-mm diameter strands. A non-shrink grout was used to prepare the grouted duct specimen, which was then cast into the slab. In addition, ordinary reinforcing bars were located in the top of the slab, parallel to the ducts.

The figure to the right is the 3-D model obtained from scanning the surface of the portion of the slab containing the ducts. The empty duct is displayed with red color, indicating strong reflections from the air interface. The grouted duct is shown in a greenish-yellow color, indicating lower amplitude reflections from the steel strands. The reinforcing bars between the ducts and to the right of the grouted duct are indicated in light blue. It is seen that at the far end of the grouted duct the image of the duct is in red, indicating a strong reflection that is characteristic of an air void.





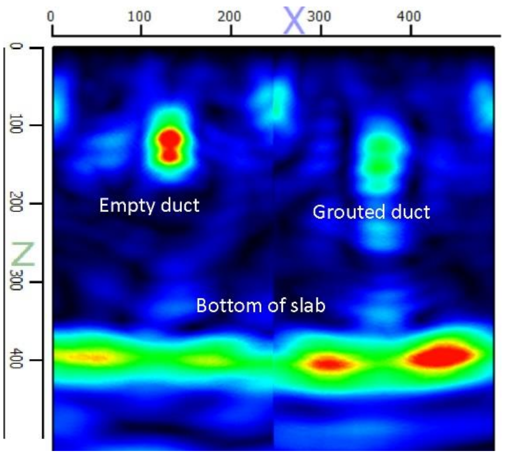
B-scan showing a cross section image of slab at location (1) with suspected void in grouted duct

The excavated duct at location (1) reveals that some of the strands are not embedded in grout

To verify that the duct is not grouted fully, the grouted duct was excavated at two locations: (1) at the end where the air void is indicated and (2) at the approximate mid-length of the duct where no air void is indicated.

The left image is the B-scan at location (1) showing a similar pattern for the empty duct and the grouted duct, which is a strong indication that the pretended grouted duct is not actually fully grouted. The corresponding photo of the excavated duct shows that indeed some of the strands are not embedded in grout. Thus, the presence of the air void is confirmed.

The following shows the results at location 2. The B-scan image shows lower amplitude reflections (from the 10 strands) at the location of the grouted duct compared with the empty duct. The reflection coefficient at the grout-steel interface is lower than at an interface with air, and that is why the grouted duct does not appear in red. The excavated portion of the grouted duct shows that the strands were encased with the grout although this was fractured during the removal of the metal duct.



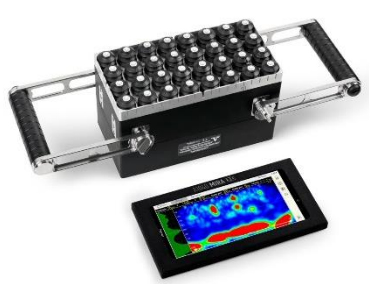
B-scan at location (2) with no voids indicated in grouted duct. The excavation reveals the strands encased with grout; some of it was fractured in the process and this exposed some wires.

MIRA 3D Specifications

- Active dry point contact (A-DPC), shear-wave transducers with wear-resistant ceramic tips and integrated pulser-receiver electronics
- Spring loaded, 32 transducers, wireless, light and compact antenna array. Extendable to 64 transducers (MIRA 3D PRO)
- The spring-loaded transducers conform to irregular surfaces, and they do not require a coupling medium, that is, testing is done in the dry
- Positioning laser beams in the antenna to facilitate its centering during scanning
- 10 to 100 kHz working frequency range
- Nominal frequency = 50 kHz
- Ultrasound speed range: 1,000 to 4,000 m/s (shear wave)
- Dimensions without handles and weight: 200 × 125 × 100 mm, 3.5 kg
  (400 x 125 x 100 mm, 5.6 kg for MIRA 3D PRO)
- Testing depth: 20 to 3,000 mm, depending on the concrete quality, member's lateral dimensions and amount of steel reinforcement
  (20 to 4,000 mm for MIRA 3D PRO)
- Rechargeable battery, 10 h operating life
- USB interface
- 3-D tomographic display in a PC with IntroView software
- Operating conditions: -10 °C to 50 °C, < 95% RH
- Error of the depth of a defect, mm, where H is the measured depth = $\pm (0.05 \cdot H + 10)$

MIRA 3D Ordering Numbers

Item	Order #
MIRA 3D control unit and protective case	M3D-1001
MIRA 3D antenna array	M3D-1002
Adjustable handle x 2	M3D-1003
Type C, AC Charger x 2	M3D-1004
USB Type C data cable x 2	M3D-1005
USB-A to USB-C cable	M3D-1006
Verification sample plate	M3D-1007
Exchangeable battery pack (inside the antenna)	M3D-1008
Carrying case	M3D-1009
IntroView software license	MIR-1003
Laptop with NVIDIA GeForce graphics card **(optional)**	MIR-1002



MIRA 3D PRO Ordering Numbers

Item	Order #
MIRA 3D control unit and protective case	M3D-1001
MIRA 3D antenna array x 2	M3D-1002
Adjustable handle x 2	M3D-1003
Type C, AC Charger x 2	M3D-1004
USB Type C data cable x 2	M3D-1005
USB-A to USB-C cable	M3D-1006
Verification sample plate	M3D-1007
Exchangeable battery pack x 2 (inside the antenna)	M3D-1008
Carrying case	M3D-1009
H-Fastener	M3D-1010
M6x10 stainless screw x 4	M3D-1011
IntroView software license	MIR-1003
Laptop with NVIDIA GeForce graphics card **(optional)**	MIR-1002