Convergence Instruments

ACAM_64

User's Manual

February 16 2022

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1 Introduction

ACAM_64 is a USB-connected acoustic camera and beamforming acoustic array. Its 64-microphone array allows it to produce 32x32-pixel (128x128-pixel interpolated) real-time images showing sound sources in its field of view.

When the optical kit is purchased, the instrument can superimpose an optical image to the acoustic image, facilitating the interpretation of the acoustic image.

2 Warnings

- Never blow air at or near the microphones.
- Do not store or operate the instrument in environments where liquids could be projected onto the microphone array. Ingestion of droplets of liquids (however small) into the pressure ports of the microphones will damage them.
- Do not store or operate the instrument in dusty environments. Ingestion of dust particles, even a few microns in size, into the pressure ports of the microphones will damage them.
- Do not store or operate the instrument at temperatures exceeding the following limits: -20 °C to 80 °C (-4 °F to 176 °F)
- Do not expose the microphones to sound pressures in excess of 160 dB_{SPL}.
- Do not mount a tablet heavier than 900g (2 lbs.) to avoid damaging the *ACAM_64*.

3 Theory of Operation

An acoustic camera produces an image where the intensity of each pixel represents the amplitude of acoustic waves coming from the corresponding direction. This is akin to an optical camera producing an image where each pixel represents the intensity of light coming from the corresponding direction.

For an optical camera, the lens focuses light coming from a certain direction to the corresponding pixel on the sensor or film. Each pixel in the image represents the intensity of light coming from a specific azimuth (angle in the horizontal plane) and elevation (angle in the vertical plane). The lens does this by slowing and delaying the light waves hitting the lens by precisely the right amount, so that all waves coming from a certain direction arrive in phase in the focal plane, at the position of the corresponding pixel.

An acoustic camera does much the same thing, except that the work of the lens is replaced by a digital computational engine that processes signals captured by an array of microphones (see ***Figure 1***).

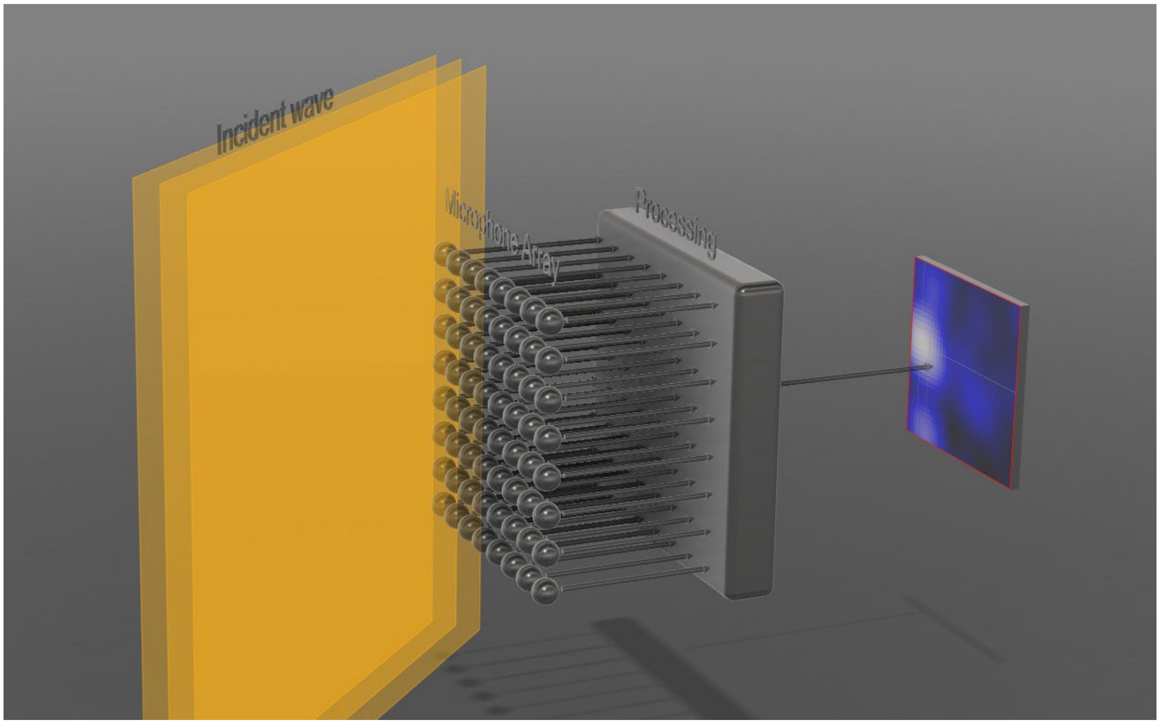

Figure 1

An array of microphones captures the sound waves hitting the array from many different directions. For every pixel, a massively parallel digital processing engine applies specific delays, and sums the acoustic signals from every microphone, so that the signals from a specific angle of incidence (azimuth and elevation) arrive in phase. ***Figure 1*** shows that process for a single pixel. Note that a different and precisely adjusted delay must be applied to every path, from every microphone in the array to every pixel in the image. In the simplest implementation, the intensity of every pixel is calculated as the energy of that sum signal, averaged over a specific length of time.

3.1 Frequency, Aperture Size, and Image Resolution

For an optical camera, as well as for an acoustic camera, the image resolution is a proportional to the ratio of aperture size to wavelength.

For an optical camera the aperture size of the camera (the size of the lens or more generally the light collector) is always very large relative to the wavelengths of interest. This is true even for very small lenses, such as those found in camera phones, where the size of the lens is a few mm, while the wavelengths of interest are in the hundreds of nm (more than 10000 times smaller). For an optical camera, resolution is rarely limited by the size of the aperture.

For an acoustic camera on the other hand, the frequencies of interest often extend to quite low frequencies (long wavelengths). For instance, the wavelength at 100 Hz is 3.4 m. To have a reasonable resolution at such low frequency would require an array of at least 8 to 10 times as large (25 to 30 m wide). This is usually not practical. Therefore, for acoustic cameras the resolution is typically poor at lower frequencies and improves only as the frequency of interest increases.

3.2 Spatial Sampling and Upper Frequency Limit

For an acoustic camera, the maximum frequency is limited by the spatial separation between two adjacent microphones. The half wavelength of the maximum frequency sampled by the microphones must be wider than the distance between two microphones. Otherwise, the array is not able to distinguish between sources that are within the field of view, and sources that are outside, leading to artifacts such as phantom images.

For *ACAM_64*, the distance between microphones is 23 mm, so that frequencies up to 7.5 kHz can be imaged properly. In practice the array is sampled at 16 kHz, with a Nyquist frequency of 8 kHz. The anti-aliasing filters in the camera ensure that the signal energy is low above 7.5 kHz.

3.3 Field of View (*FOV*)

The field of view of a camera represents the number of degrees that the camera can see (that are represented in the image) in the horizontal plane (azimuth) and vertical plane (elevation).

For *ACAM_64*, the field of view is the same in azimuth and elevation (the image is square). There are two possible settings:

- **90 degrees** (-45 degrees to +45 degrees from left to right and from bottom to top)
- **60 degrees** (-30 degrees to +30 degrees from left to right and from bottom to top)

3.4 Audio Beamformer

The acoustic “sum” signal corresponding to any pixel position is available and can be streamed out of the processing engine, to be listened to. This process is called “beamforming”. The microphone array can be digitally steered to the angle of incidence corresponding to any pixel in the field of view and focus on that source. In addition, since the image shows the azimuth and elevation of the loudest source in the field of view of the camera, the beamformer can be made to follow that “hot-spot” as it moves across the field of view.

4 Features

- 32x32 real-time image of the acoustic environment, displayed as a thermal map. *Instrument Manager* presents a 128x128 pixel interpolated image.
- Ready to run application provided for Windows.
- Optional Optical Kit allows the superposition of optical and acoustic image, making the interpretation of the acoustic image easier.
- The beamformer can capture the audio signal at any specific direction within the field of view of the camera
- Using the provided application, the audio capture can track the source direction, following the source as it moves within the field of view of the camera.
- Frequency response can be adjusted by defining lower and upper frequency limits.
- Adjustable field of view: 60 deg or 90 deg.
- Adjustable image persistence from 10ms to 10s
- Massively parallel real-time all-digital design. Can build every pixel of the image from every sample captured by every microphone in the array.
- Open communication protocol allows applications designed by OEMs
- Editable individual custom ID for easier instrument management.

5 *ACAM_64* Applications

- Detection, tracking and recording of acoustic sources.
- Soundproofing.
- Mechanical product design for acoustical performance.

6 Getting Started

6.1 Software Installation

- On the PC that is used to setup the instrument, run *Instrument_Manager_Installer.exe*. This installs the *Instrument_Manager* application, as well as its USB driver and documentation.

Note: Perform the software installation above BEFORE connecting the instrument to the PC for the first time. The installer includes the USB driver of the instrument, without which the PC will not recognize the instrument.

6.2 ACAM_64 Hardware Installation

1. Connect the instrument to an available USB port on the PC

2. Verify that the PC properly detects the instrument and wait for the PC to load the driver. In case of doubt see section ***Troubleshooting***

6.3 Optional Optical Kit Installation

6.3.1 Mounting of the Optical Camera Onto *ACAM_64*

To mount the optical camera onto *ACAM_64*, follow these steps:

1. Attach the camera bracket to the back of *ACAM_64*, using the tablet mount threaded adapter (see **Figure 2** and **Figure 3**). Note that the threaded adapter can still be used to attach a tablet mount if required.

2. Clip the camera to the top of the mount (see **Figure 4** and **Figure 5**). Press both panels of the camera clip to secure the camera onto the bracket.

Figure 2

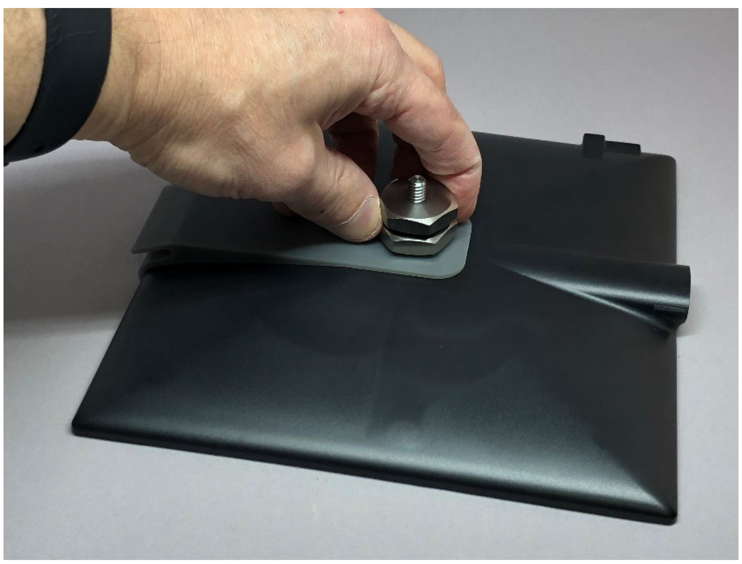

Figure 3

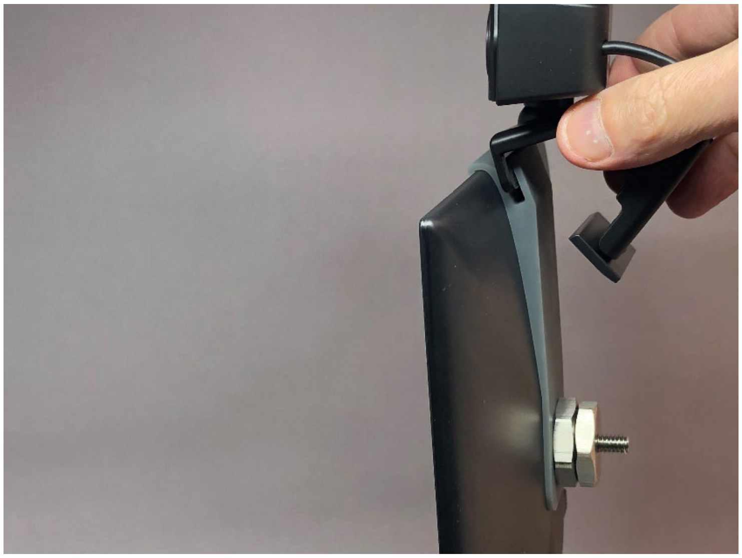

Figure 4

Figure 5

6.3.2 Connecting the Optical Camera

1. Connect the optical camera to a USB port of the PC. The first time around wait for the PC to detect the camera and load its driver.

2. Go to the PC's Settings. Make sure the PC does not use the microphone of the new camera as the default microphone for the PC. If it does so, change the default audio input device and the default communication input device back to the PC's usual microphone.

3. Connect the *ACAM_64* acoustic camera to another USB port on the PC. If it is the first time, wait for the driver to load and the instrument's LED to turn green.

4. Start the *Instrument Manager* application.

6.3.3 Adjusting the Parallax

The location of the optical camera is offset from the center of the *ACAM_64* microphone array. So, it is important to orient the optical camera so that the acoustic image and the optical image are aligned.

To properly align the two images, follow the instructions below:

1. Use a source of white noise. Many smart-phone applications can generate white noise of a controlled amplitude. For instance, *Tone Generator Pro* from Performance Audio https://www.performanceaudio.com/apps/ . Best results are obtained with a compact white noise source of wide frequency content. Do not use a pure tone as a source, as it will be coherent with reflections on walls, ceiling and floor and create distorted images. There are also many white noise audio files that can play from various YouTube channels. It does not matter what the actual source is, as long as it is relatively compact, and the generated noise has a wide frequency content.

2. Place the source of white noise in front of the camera at the distance where the actual source to be imaged is expected to be. The alignment is slightly dependent on the distance from the camera, especially for measurements at close range, where the parallax error is largest.

3. Orient *ACAM_64* towards the source so the source is clear and roughly in the middle of the acoustic image.

4. Tilt and turn the optical camera on its swivel, so the optical image of the source is aligned with the acoustic image (see **Figure 6**).

Figure 6

7 Instrument_Manager Application

7.1 Starting the Application

To control an *ACAM_64* using *Instrument_Manager,* proceed as follows:

1. Connect the instrument to an available USB connector on the PC.

2. Make sure that the operation LED turns green. If not, review the installation procedure, or see section ***Troubleshooting***

3. Optionally connect the optical camera to a USB port on the PC.

4. Go to *Start\All-Programs\Convergence_Instruments\Instrument_Manager* and run *Instrument_Manager.exe*.

    a. If the application detects both the *ACAM*_64 and the optical camera, it presents a window like in ***Figure 7***.

    b. If the application detects only the *ACAM_64*, it presents a window like in **Figure 8**

    c. If the application detects neither *ACAM_64* or the optical camera, it opens in *File-Playback* mode. In that mode it only allows the playback of pre-recorded .acam movies.

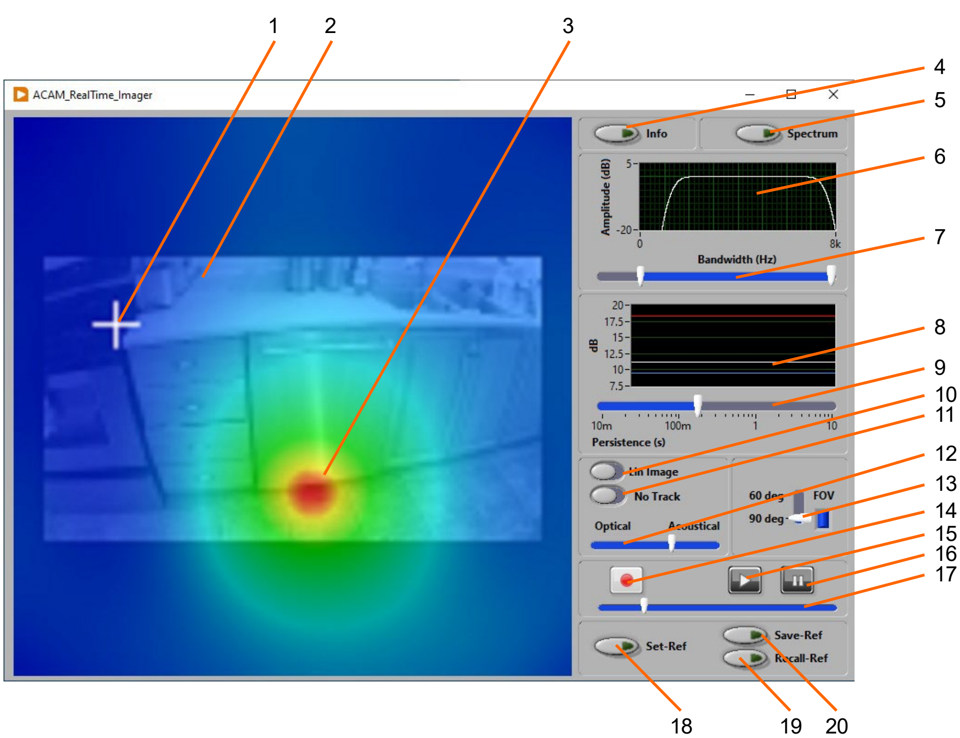

Figure 7

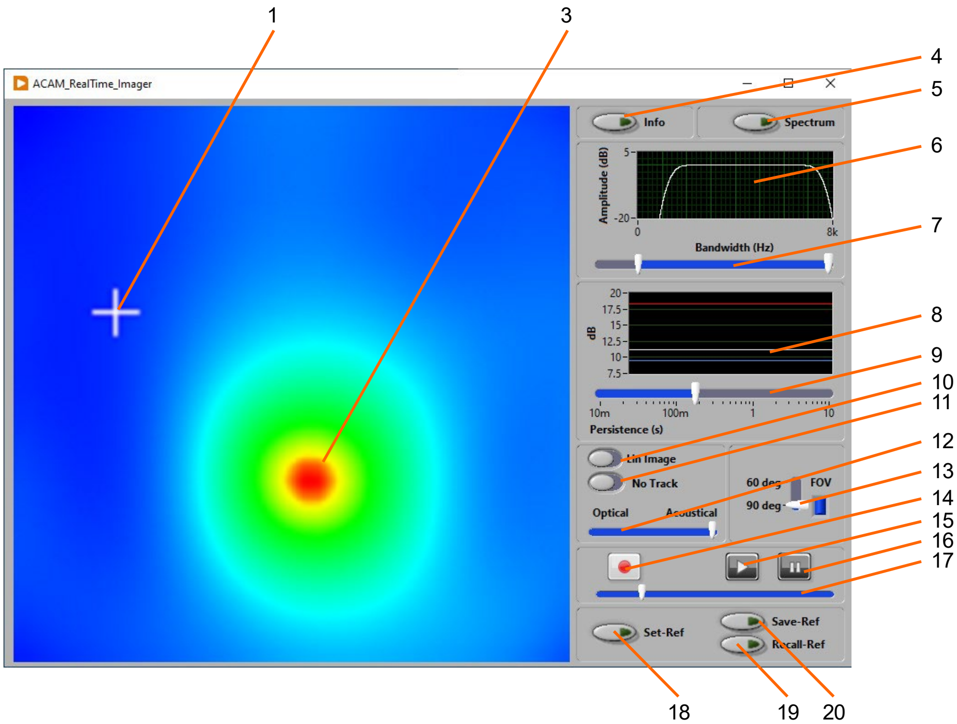

Figure 8

1. Cursor
2. Optical Image
3. Real-time acoustic image
4. Instrument information
5. Spectrum display button
6. Instrument frequency response
7. Frequency response controls
8. Trace of past levels (in dB_{SPL})
9. Image persistance control
10. Lin/Log image mapping
11. Auto-Track button
12. Optical image relative intensity
13. Field of view button
14. Record button
15. Play-back button
16. Pause button
17. Scrubber bar
18. Set reference image button
19. Recall reference image button
20. Save reference image button

7.2 Main Functions

The front-panel of the application has several sections:

7.2.1 Acoustic Image

The acoustic image field displays the real-time acoustic image captured by the instrument. The image is auto scaled in contrast and brightness.

7.2.2 Optical Image

When the optical camera is connected, the optical image is superimposed onto the acoustic image. The scale of the optical image changes depending on the Field of View setting of the *ACAM_64* (see **Figure 9** (FOV: 90 deg) and **Figure 10** (FOV: 60 deg)).

7.2.3 Cursor

In *Tracking* mode, the cursor follows the highest pixel in the image. That is also where the beamformer is pointing.

In *No-Track* mode, the cursor can be set by clicking anywhere in the window, to steer the beamformer to a specific location. The white curve in the trace of past levels shows the level measured at the position of the cursor.

7.2.4 Instrument Information Button

When this button is pressed the application presents several fields of information about the instrument. The *User_ID* can be set to any alphanumeric string (limited to 32 characters). This is used to identify the instrument to something pertinent to the user.

7.2.5 Spectrum Display Button

When this button is pressed the real-time spectrum of the beamformer's output signal (at the location of the crosshairs) is presented in a separate window. Note that the calculation of the spectrum adds to the computational load of the PC, and depending on the speed of the PC, may limit the number of acoustic and optical frames displayed per second. The spectrum window can be moved at will. To close it, simply press the button again.

Note that the spectrum can only be displayed when the beamformer's output is not being streamed to the USB Audio interface of the PC. If no spectrum is displayed, open the Windows settings, and make sure an audio input other than ACAM_64 is selected as the PC's audio input.

7.2.6 Frequency Response

This shows the frequency response of the camera.

7.2.7 Frequency Response Controls

This pair of sliders select the lowest and highest frequencies processed by the acoustic imager. Note that the resolution of the camera is dependent on the frequencies that it is imaging. Lower frequencies produce images that have a very low resolution, while higher frequencies can show finer details. The two controls allow the response of the imager to be selected between a very wide frequency range (the default) to a very narrow one. By choosing a very narrow band and changing this band different images can be produced to show the effects of various frequency components in a source.

7.2.8 Trace of Past Levels

The red curve presents the highest level in the image (in dB_{SPL}), as a function of time. The white curve shows the level at the location of the cursor. The blue curve presents the lowest level in the image. These levels represent the contribution of the corresponding source to the measured level at the location of the camera.

7.2.9 Persistance Control

This control adjusts the persistence of the image. This is the equivalent of the exposure time for an optical camera. A persistence of a 200 to 300 ms is recommended for most applications. A longer persistence will allow the averaging of the image over longer time periods, and therefore present images with less flicker. But events occurring at short intervals will blur from one image to the next. A shorter persistence will allow the tracking of more dynamic events, at the expense of noisier images.

7.2.10 Lin/Log Button
In Lin mode, the brightness of the pixel is proportional to the pressure-squared received from the corresponding direction. In Log mode, the brightness of the pixel is proportional to the level in dB_{SPL} received from the corresponding direction. Log mode allows the representation of a wider dynamic range of levels, but it also tends to produce images with less sharp details.

7.2.11 AutoTrack Button
When this button is pressed, the audio beamformer will track the highest-intensity pixel in the image. The audio produced by the camera will automatically follow and focus on the source as it moves across the field of view. When the mode is not set to AutoTrack, the cursor can be moved manually to any pixel in the image.

7.2.12 Optical Image Intensity
This slider adjusts the relative intensity of the optical and acoustic images. It allows the presentation of fully optical to fully acoustic images, with all degrees of relative intensity in between.

7.2.13 FOV Button
The user can choose between two fields of view: 60 deg or 90 deg. Changes from one field of view to the other take time, as the camera must be completely reprogramed for the new field of view. The choice of field of view is persistent across connections/disconnections.

The optical image is also scaled to reflect the field of view of the acoustic image (see **Figure 9** and **Figure 10**).

7.2.14 Record Button
A movie can be recorded by pressing this button. The recording starts when the button is pressed and stops when the button is pressed for a second time. When the recording stops the application will ask where to store the recorded file.

7.2.15 Playback Button
A previously recorded movie can be played back by pressing the *Play* button. The application then asks to point to the recorded file. The recorded file plays at normal speed. The playback can be paused by pressing the *Pause* button at any time. After the complete file has played, the playback system is left in pause mode at the last image of the file. Pressing the *Play* button while a file is being played will abort the playback and present the real-time acoustic image back.

7.2.16 Pause Button
Pressing the *Pause* button during playback will pause the image. At that time, the scrubber bar can be moved manually to quickly change locations in the file.

7.2.17 Scrubber bar
While the playback is paused, the scrubber bar can be used to quickly move the playback to a new position in the file.

7.2.18 Reference image
Working with a reference image can be useful in two situations:

- **When working at extremely low levels:** At acoustic levels below 5 to 10 dB_{SPL}, the microphone's intrinsic noise components can lead to a phantom image. Typically, the image shows a bright spot in the center of the image due to microphone noise components that are in-phase between all the microphones. Because that image is calculated from microphone noise, and not from real acoustic components it will stay fixed when the camera is panned to another direction.

- **When taking differential measurements:** In some situations, one wants to study the difference between the acoustic levels measured with some source active, and levels without the source. In that case using a reference image can also be useful.

After setting a reference image, it will be subtracted from all subsequent displayed image. So, when working with a reference image it is important to make sure that the reference image's levels always be lower than the levels measured subsequently. This way all the pixels of the resulting difference image will always have a positive resultant energy. For that to be true:

- Reference images resulting from a static field, or from the intrinsic microphone noise should be taken with a long time constant, so they are measured accurately.

- Make sure to avoid extraneous noises when taking the reference image. This is especially the case when removing phantom images due to microphone noise components. In that case, levels are already so low that a simple mouse click can corrupt the reference image.

- When taking differential measurements to compare the field with a source to be studied to the field without, the reference image should be taken WITHOUT the source being studied. Subsequent images should be taken WITH the source. That means that the reference image should represent the background field. The subsequent difference images represent the field that exists on top of the background.

- Do not change the frequency response setting between taking the reference image and subsequent measurements of the difference images. The shape and indicated levels of a reference image can change when the frequency response of the sensor is changed.

Note: *The reference image is captured before all other processing is performed on the image. That reference image represents the energy being measured by the sensor. It is always captured in linear scale (in* Pa^2*), and never interpolated. The difference between the raw sensor image and the reference image is calculated before all further processing such as interpolation, transformation to log scale,* dB_{SPL} *calculations… etc.*

Note: *Recordings are saved WITHOUT subtracting a reference image, even if one has been set. However, the playback will apply a reference image if one has been set or recalled. What is recorded is the raw sensor output.*

Note: *A reference image can be set during playback. In that case, the reference image is taken as the image displayed when the* Set-Ref *button is pressed.*

7.2.18.1 Set Reference

The button captures the present image and uses it as a reference. Subsequent images represent the difference between the raw image and the captured reference image. The reference image can be captured from a real-time display, or a playback of a previously recorded movie.

Simply press the button again to clear the reference

7.2.18.2 Save Reference

The button saves a captured reference for use later. This is typically useful when working at extremely low levels, to remove the image due to microphone noise. In that case, make sure the frequency response controls stay the same between the captured reference and the images taken subsequently. Note that a reference must have been set prior to saving it.

7.2.18.3 Recall Reference

The button recalls a reference image that has been captured and saved previously. All subsequent images are difference images between the sensor output and the recalled reference image.

Simply press the button again to clear the reference

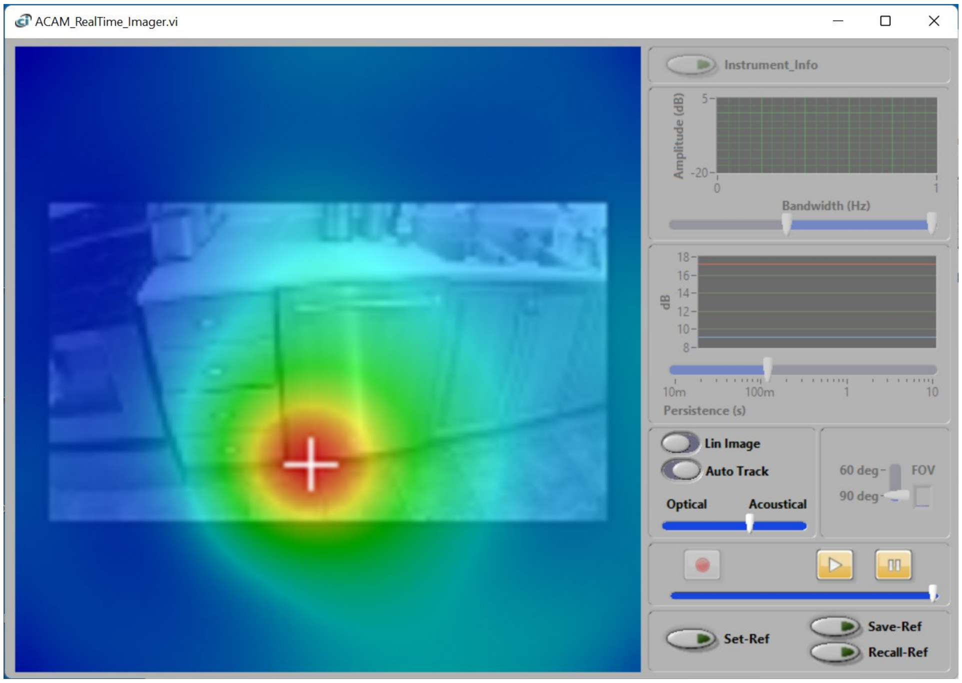

Figure 9

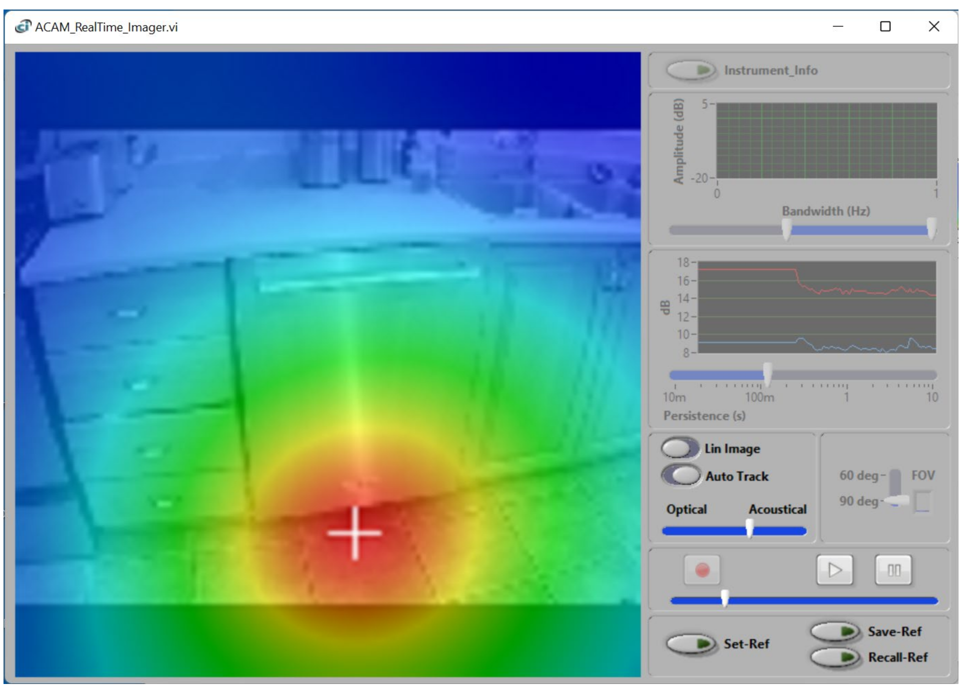

Figure 10

8 Troubleshooting

8.1 USB Driver Installation

If the *Instrument_Manager* application is unable to communicate with the *ACAM_64* it may be because the USB driver failed to install properly. To check the USB driver installation, follow the procedure below:

1. Make sure the *Instrument_Manager* application has been installed BEFORE the instrument is connected to the PC for the first time. If not, disconnect the instrument and install *Instrument_Manager*.

1. If necessary, take the PC out of stand-by.

2. Connect the instrument to an available USB port on the PC. The first time the instrument is connected it may take some time for the PC to recognize the instrument and load its USB driver. Wait until the instrument has been recognized by the PC. If necessary, open the Settings page of Windows, and observe that the PC has recognized the instrument.

3. Make sure the charge LED lights-up and turns green after 1 to 2 s. If not, make sure that the PC's USB port is functional, and that the USB cable is not damaged. If necessary, try on a different PC, and/or with a different USB cable. If the PC does not recognize the instrument, go to step 4

4. If the PC does not seem to recognize the instrument, open the *Device Manager* on the PC. This is usually found in *Control Panel – System and Maintenance*.

5. Just after connecting the instrument to the PC, observe that the *Device Manager* window refreshes.

6. Verify that the following 3 items are created:

    a. **Microphone (ACAM-Audio)** should be created in the Audio Inputs and Outputs section.

    b. ***DDCI Platform*** should be created in the list of devices.

    c. **USB serial device (COM x)** should be created in the Ports section. It is possible that your PC has more than one of these ports installed, each one corresponding to a different device.

7. If an unknown item appears, or an item with the above names is found but has an exclamation mark (indicating a problem) beside it, disconnect the device and try re-installing the driver (see step 8).

8. For a manual installation of the driver, contact support@convergenceinstruments.com

8.2 Electrostatic Discharges

When the instrument is subjected to electrostatic discharges it can lose communication with the host PC. If that happens, simply disconnect, and reconnect the USB cable, and restart the application.

9 Mounting a Tablet

A tablet can be mounted to the back of *ACAM_64* to present the acoustic image while aiming the camera forward.

Note: Do not mount a tablet heavier than 900g (2 lbs.) to avoid damaging the *ACAM_64*.

To mount a tablet onto the *ACAM_64*, proceed as follows:

1. Thread the tablet mount adapter to the back of ACAM_64. If using an optical camera, position the optical camera bracket prior to threading the adapter (see **Figure 11** to **Figure 12**). Note that the adapter must be threaded with the locknut on top. Be careful not to over-tighten.

2. Make sure the locknut is all the way down. Thread the tablet mount onto the adapter (see **Figure 13** to **Figure 15**)

3. Place the tablet in the tablet mount (see **Figure 16**)

4. While holding the tablet in a horizontal position, use the wrench to tighten the locknut against the tablet mount (see **Figure 17**). Be careful not to over-tighten.

Figure 11

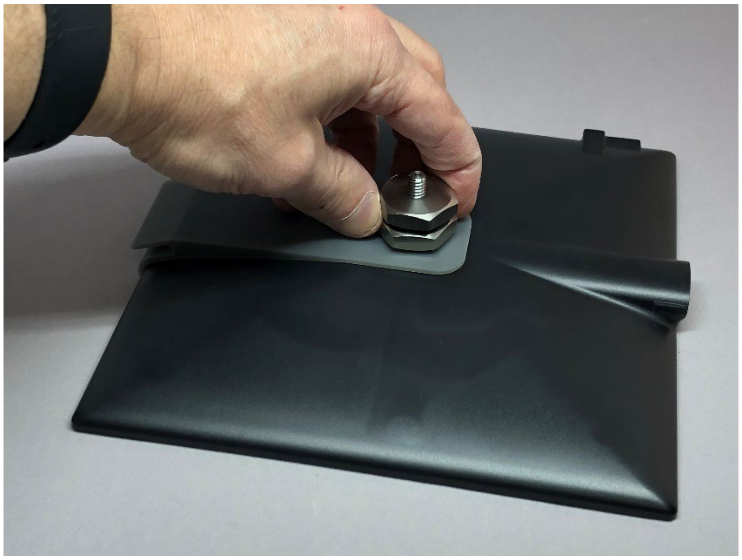

Figure 12

Figure 13

Figure 14

Figure 15

Figure 16

Figure 17