Realtime Vision System

User Manual

Version 0.2.2

Resonon Inc.

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1 Overview

1.1 About

The Realtime Vision System utilizes hyperspectral imaging and powerful machine learning algorithms to produce accurate and real-time classification or grading of objects. Because the system relies on hyperspectral imaging, it can often differentiate objects that appear identical to the human eye. This document will guide you through the process of setting up the system and training it to classify objects, whether you are trying to distinguish genuine from counterfeit products, quantify a material property such as moisture content, detect foreign material or blemishes, monitor homogeneity, or sort a mixed stream of materials.

Major system components include the hyperspectral imager, the computer and software, and a lighting system. Also essential to the system's operation is a conveyor belt to carry objects past the scanning imager, a referencing system for calibration, an encoder, and an USB encoder adapter to synchronize the imager's operation with the conveyor belt movement.

There are three tiers of RVS. RVS Acquire can be used quickly acquire large quantities of datacubes for analysis with Spectronon or other software. RVS Analyze additionally includes the ability to train and run classification or regression models. RVS Automate further provides the ability to generate an output stream to other machinery, databases, or processes.

1.2 Software Acquisition, Download, Updates, and Licensing

To purchase RVS, please contact Resonon at support@resonon.com. When an updated version of RVS becomes available, you may download the latest version on Resonon's download page (downloads.resonon.com). If you are connected to the internet when launching RVS, it will check for updates and let you know that an update is available. For licenses that are approaching expiration, a message will inform you of the pending expiration. This will occur 3 months, 1 month, 2 weeks, and every day for the last 10 days before the license expires. Please contact us for a license renewal.

> **Note**: Even *perpetual* licenses are set to expire and be renewed annually (at no additional cost).

2 Mechanical Components Setup

2.1 Imager Compatibility

The RVS software is currently compatible with the Pika L, Pika L-F, Pika L Gig-E, Pika IR, Pika IR+, and Pika XC2 (although the Pika XC2 is typically not recommended due to extremely high data volumes).

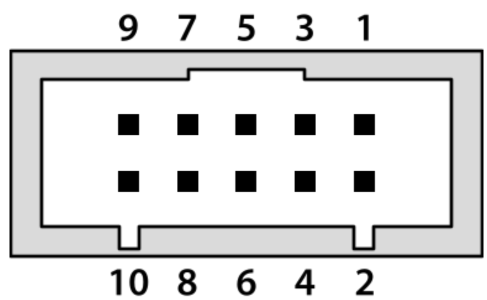
2.2 Components Setup

It is essential to align your system's mechanical and optical components to ensure the system's optimal operation. General setup operations include the following.

1. Setting the camera height so that the entire width of the conveyor belt fills the imager's cross-track field of view.
2. Ensuring that the imager's cross-track field of view is perpendicular to the conveyor belt motion direction.
3. Adjusting the imager's position and angle, in coordination with the lighting, to optimize the amount of light reflected by the objects onto the imager. The fine-tuning of the lighting will be explained below in this guide.
4. Establishing a connection from an appropriate belt encoder to the Realtime Vision System.

   Note: Appropriate encoders are incremental quadrature encoders. They have 3-channel differential signaling, typically with a 10-pin connector. Resonon can provide the QSB-D model USB adapter to complete the connection with the belt system. The pinout setting for this adapter is below:

1	Digital I/O, Channel 0
2	Ground
3	Index-
4	Index+
5	A-/PWM0-
6	A+ or EAN0 or PWM0+
7	+5 Volts
8	No connection
9	B-
10	B+



* Pin 6 EAN0 is an A/D input designed for the MAE3-A10 and MA3-A10 analog output encoders. It can be used as a generic 10-bit A/D input (0-5V range). * Pin 6 PWM0+/PWM0- is a differential pulse width modulation input designed for the 10 or 12-bit PWM output of the MA3/MAE3 encoders.

3 Data Acquisition Setup

Once the mechanical and optical components are installed, they must be connected and powered in the following way:

1. The computer is connected to a power source.
2. Depending on the specific imager used, the imager is either connected to the computer's ethernet port that is labeled for the imager (Pika IR, IR+, and Pika L Gig-E), or to the computer's USB 3.0 port (Pika L, Pika L-F, and Pika XC2).

3. If using a Pika IR, Pika IR+, or Pika L Gig-E: imager is connected to a power source (standard wall outlet) using the provided cable. Note that the Pika L, Pika L-F, and Pika XC2 are powered through the USB data cable so no other connection is required.
4. Encoder is connected to the computer via a USB port.
5. Light source is on. It is advisable to turn on the light source 15 to 20 minutes before beginning scanning for temperature stabilization, thereby ensuring repeatable/reliable operation.

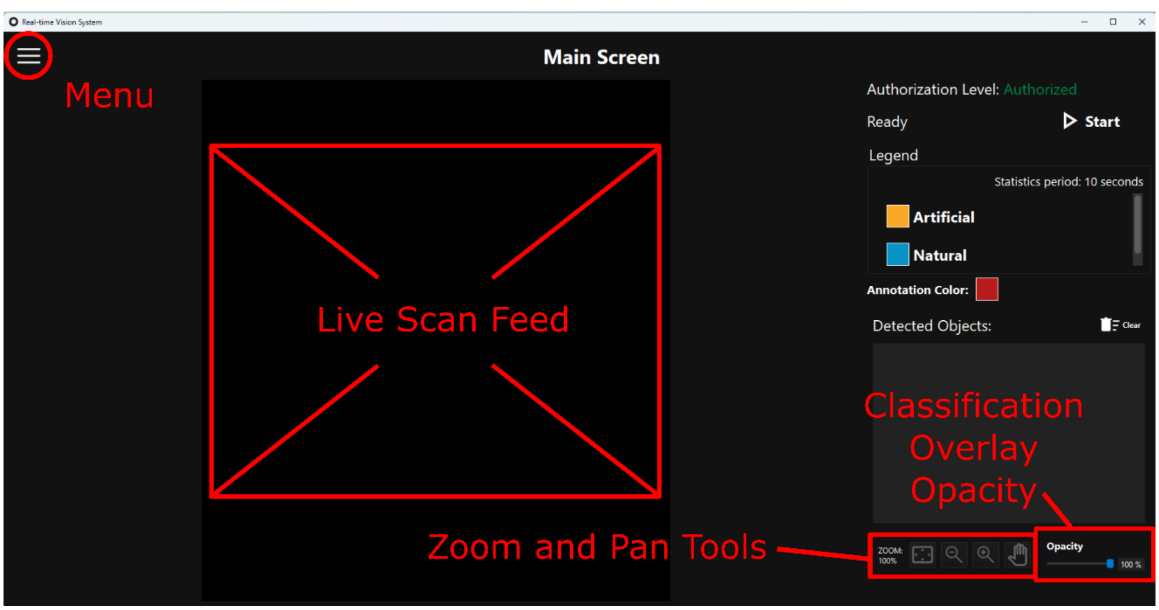
4 SOFTWARE

The Realtime Vision System (RVS) software can be configured to run at boot in full screen or launched in the normal manner by the user after boot. It will automatically detect the peripherals (imager and encoder). If you are launching the software with a new encoder, please follow the prompts and accept the requested changes.

> **Note**: The window for configuring the encoder may pop up behind the main RVS window. Use Alt-Tab to bring it to the front.

If the imager is not connected, you will see an error message informing you that "Camera Initialization Failed." In this case, exit the software, check the imager connection, and launch the software again. To exit the software, click ≡ *(Menu)* in the main screen's top left corner, and then ⏻ *Exit*.

The main screen is also the standard operating screen. Until you set up the system, it will be mostly empty. Then, depending on whether you are running in object detection mode, or in pixel classifying mode, the appearance of the right panel will vary slightly.



Main Screen

Click ≡ *(Menu)* in the main screen's top-left corner to view the drop-down main menu and access any sub-screens.

> **Note**: Until *authorized*, many of the menu items will be hidden. Also, until the Camera Setup is completed, some menu items will be grayed out and unavailable.

To exit any sub-screen, click ← (*Back*) next to the screen's name in the top left corner of that screen.

4.1 MAIN MENU ITEMS DESCRIPTION

Lock	Enables an administrator to lock the system for normal operation (after the system has been set up)
Authorize	Enables an administrator to unlock the system and access back-end training and settings.
About	Contains software version information and other legal information
License	Brings up the software license information and allows you to install a valid license to use the software
Settings	Allows the user to change between Object and Pixel modes, configure the Object Output Format, display statistics, etc.
Camera Setup	Accesses a suite of tools to focus and calibrate the imager
Encoder Setup	Sets the encoder count and belt direction
Logs	Accesses logs of various operations carried out on the system for future diagnosis and/or improvements. The logs are simple text files that are recorded locally on your machine
Datacube Recorder	Collect datacubes that can be opened and analyzed in Spectronon. The datacubes can also be opened later in the training screen.
Training	Contains tools to train the vision system to perform the desired task
Object Detection	Provides tools to configure the object detection functionality
Benchmark Model	Checks the speed at which the computer can process camera data using the currently active classification or regression model
Exit	Shuts down the Realtime Vision System software

4.2 STEP BY STEP

4.2.1 AUTHORIZE

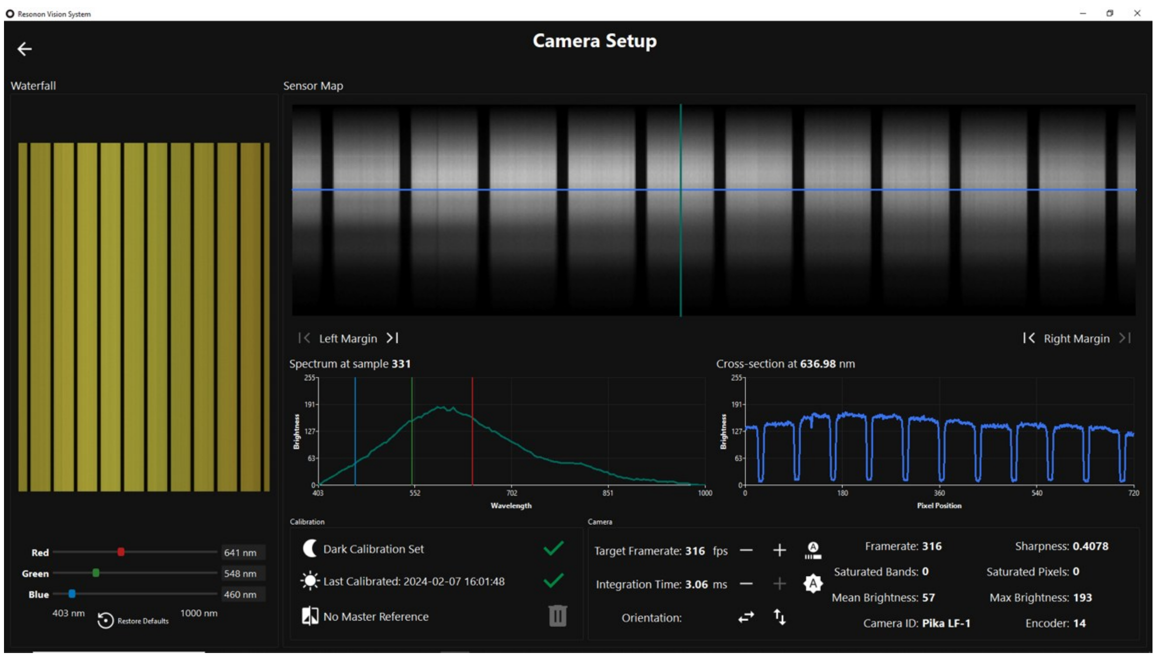
Different functionality of the software is accessed with different codes, allowing managers to determine which personnel have access to different aspects of the software (setup, training, running, etc). Click the *Authorize* item in the Main Menu and enter in the appropriate code.

4.2.2 INSTALLING THE LICENSE

You must first install the software, then access the License screen by clicking ≡ *(Menu),* and then *License*. If you have not yet obtained your license file, copy the System ID (there is a *copy to clipboard* button next to the system ID) and contact us at support@resonon.com with that system ID. Assuming that you have purchased a license, we will use that System ID to generate a license file that will be valid for your specific computer. Once we've emailed you the license file, save it somewhere on your computer and go back to the License screen to install it. Click on *Install License File* in the bottom left corner of the *License* screen and follow the instructions. Exit the *License* screen by clicking *Dismiss* in the bottom right corner.

4.2.3 The Camera Setup Screen

Click ≡ *(Menu),* and then *Camera Setup* to open a screen that contains tools to calibrate and align the imager for a specific setup. Most of these steps need only be done once unless the camera position or other setup parameters are changed. The *White Reference Calibration* is the exception to this rule; it should be done on a regular basis. The schedule for white reference calibration depends on the environmental conditions, shift or downtime constraints, and the stability of illumination.



Camera Setup screen

On the *Camera Setup* page, the top left image shows RGB spatial data as a function of time. This is the *Waterfall Scan Feed*, where the top of the waterfall is by default the most recently scanned line by the imager. You may change the direction of the live feed, or flip the image, using the *(Flip)* and (*Reverse)* toggle icons at the bottom center of the screen.

The top right image is a *Sensor Map*. To understand this image, it is useful to explain that the imager is a scanning imager that captures a single line of light at a time in the cross-track direction of the conveyor belt, filling the sensor's x-axis. The light is then spread into its spectral components, filling the sensor's y-axis. Therefore, the *Sensor Map*'s x-axis is a direct spatial representation of the live objects being imaged but its y-axis conveys the spectral makeup of each location along the x-axis.

Clicking anywhere on the *Sensor Map* with the crosshairs selects a point in the two-dimensional position/wavelength space. The center panel below the *Sensor Map* plots the brightness vs wavelength at the crosshair's spatial coordinate. The right panel below the *Sensor Map* plots the brightness vs cross-track position at the crosshair's wavelength coordinate, which can be useful when focusing the imager.

4.2.4 Aligning the Light Source

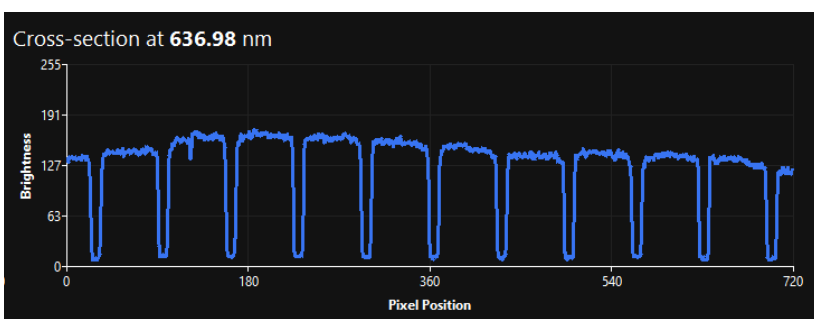
Place the white reference material on the belt in the imager's field of view. Ensure that the white reference covers the entire imager's linear field of view.

If using our SpectralSight system, loosen the thumb knob that locks the line light in position and swivel the line light back and forth across the imager's field of view until you maximize the image's brightness, then re-tighten the thumb knob. Red regions on the sensor map indicate saturated pixels. Correct saturated pixels by adjusting the *Integration Time* using either the **+** and **–** buttons or the *Auto Expose* button in the *Camera* panel near the bottom of your screen.

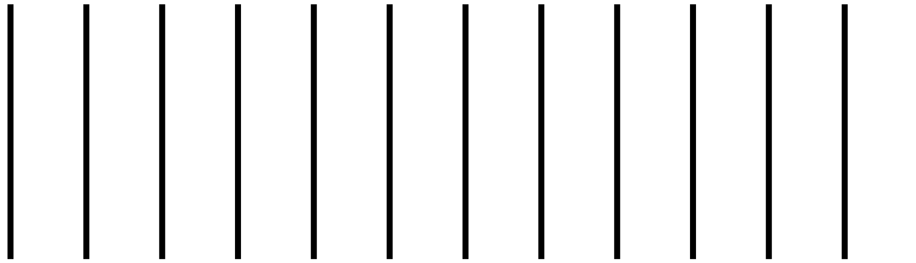
If using a custom lighting system, use all adjustments at your disposal to make the illumination's footprint match the imaging footprint, thereby ensuring uniform illumination across the belt, and maximizing the illumination to minimize imaging time.

4.2.5 Adjusting the Focus

Place a *Focusing Sheet* on the belt in front of the imager (any paper with sharp lines that run parallel to the belt will work). Unlock lens's focusing mechanism. On most of our lenses, this means loosening the Allen screw on the silver collar. Our 25 mm IR lenses do not have collar or a locking mechanism. Rotate the lens back and forth until you optimize the focus. This may require several full rotations of the lens. Several tools can help optimize the focus. First, the line sharpness can be visually optimized in the *Sensor Map*. Second, you may maximize the depth and steepness of the dips in the *Brightness vs Pixels* plot (the dips in intensity represent the dark lines on the paper). This is shown in the plot below. Finally, you may adjust the focus by maximizing the *Sharpness* index number shown below the plot.



4.2.5.1 Focusing Sheet



4.2.6 Setting the Integration Time

Keep the white reference material on the belt, making sure that it is clean, and that the imager's entire field of view lands on the reference material, (the entire width of the *waterfall scan feed*, and *sensor map*, are white). Click *Auto Expose* near the bottom of the screen. You can also adjust the integration time manually with the **-** and **+** buttons.

> **Note**: Integration time can limit achievable framerates. If higher framerates are desired more light may be necessary.

4.2.7 Setting the Target Framerate

You may decrease or increase the target framerate using the **-/+** adjustment buttons to the right of the *Target Framerate* label or set it automatically to the maximum possible framerate by clicking *Automatic Framerate* at the bottom of your screen. It is normally recommended to use the highest framerate available.

4.2.8 Imager Calibration

The *Calibration* panel is at the bottom and center of your screen. Click *Record Dark Reference*. Follow the prompt to block the lens with the lens cap and click to continue. This step corrects readings for the baseline sensor activity in the absence of light. This only needs to be done once during the initial system setup.

Next, click *Record White Reference*. You will be prompted to place the supplied white reference material in the imager's field of view and click to continue. This step allows the software to account for sensor response and spatially nonuniform illumination effects. This step needs to be performed frequently depending on the environmental conditions, shift or downtime constraints, and the stability of illumination.

4.2.9 Master Reference

The two last icons in the *Calibration* panel allow you to set ( ) or delete ( ) a Master Reference. By setting a master reference, any subsequent *White Reference Calibration* that differs substantially from the master reference will trigger a warning message. **The warning suggests that something may have gone wrong with the setup such as a burnt-out bulb in the lighting system, a change in the camera or**

lighting alignment, or a dirty white reference, and should always be investigated before proceeding further.

4.2.10 Completing the Camera Setup

You may now exit the *Camera Setup* screen using the ← (*Back)* button at the top left of your screen.

4.3 Encoder Setting

The encoder function is to ensure that the imager's frame capture rate is properly synchronized with the conveyor belt's translation. This, in turn, ensures that images appear with the correct aspect ratio, even if the speed of the conveyor changes. Therefore, setting the *Encoder Counts per Frame* is equivalent to setting the image's aspect ratio.

4.3.1 Setting the Encoder Counts Per Frame

Navigate to the *Encoder Setup* screen from the main menu. The first step is to check the direction of the encoder counts as the belt is running in its desired 'forward' direction. This is done by running the belt and observing whether the *Encoder Position* number is increasing or decreasing. If the number is decreasing, check the *Reverse Direction* box. If the number is increasing, the box should be unchecked.

> **Note**: The *Reverse Direction* box just configures the software on the expected direction of the encoder counts, there is no need to change the direction of the belt travel.

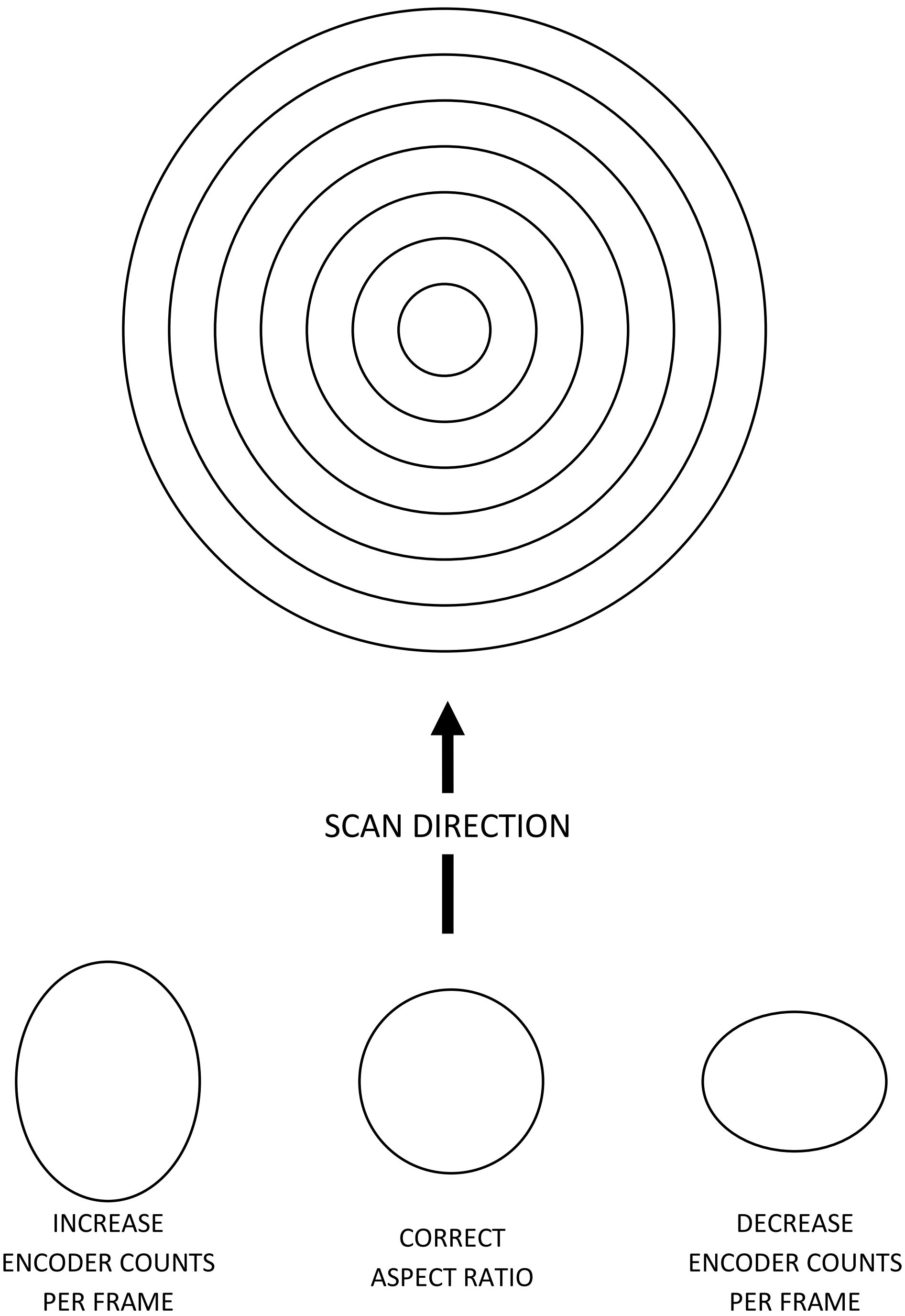
Place the included circular target (or flat circular object of the correct size) on the belt. Click the • *Start Camera* button. Remember that the software will not start recording until the encoder detects belt movement. Start running the belt. After a full circle has been imaged you may stop the belt, and then end the recording by clicking ▪ *Stop*.

> **Note**: If the software does not start recording even when the belt is in motion, the *Encoder Direction* setting may be incorrect. In this case, stop the belt, ▪ *Stop Recording*, check or uncheck the *Reverse Direction* box.

Now press the *Detect Target* button. This feature will attempt to automatically set the correct *Counts Per Frame* for unity aspect ratio (also referred to as *square pixels*). This feature will only work if the circular target is the only object in the scene, and that it has sufficient contrast. If the target appears to be properly detected, press Confirm to set the *Counts Per Frame*.

To check the setting, record another cube of the circular target. Observe the image of the circle as it appears on the screen. If the circle is circular (proper aspect ratio) the encoder setting is correct. If the circle appears compressed along the belt's direction of travel, the imager is not taking enough frames and you need to reduce the *Encoder counts per frame*. If the circle appears stretched, you must increase the *Encoder counts per frame*.

4.3.1.1 ASPECT RATIO CALIBRATION SHEET

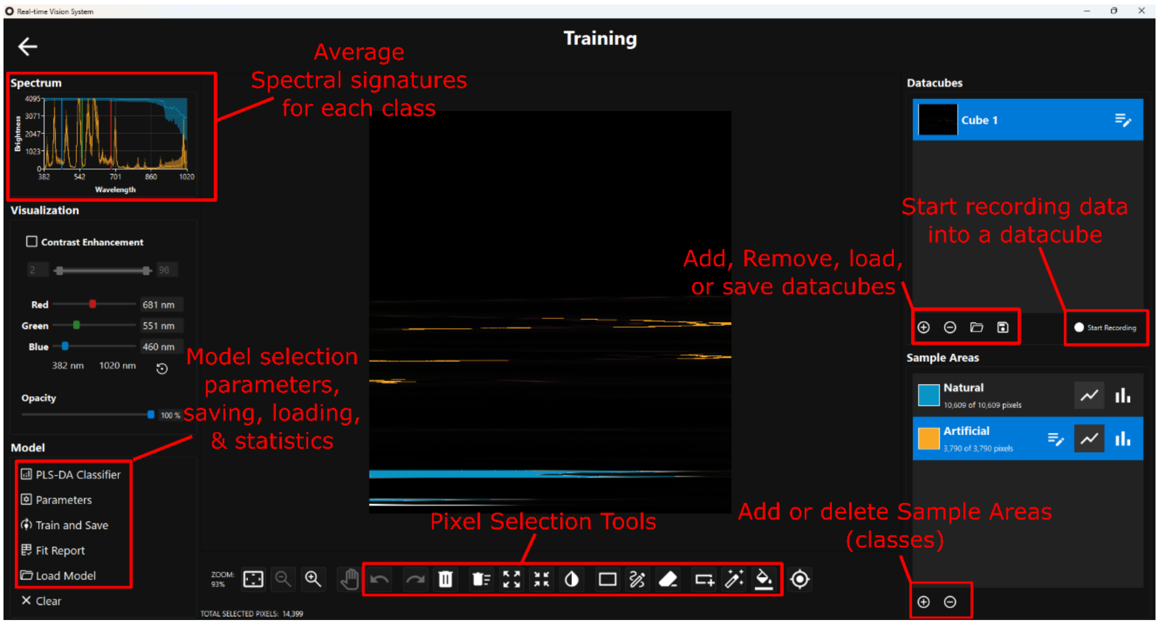


Note: this sheet will only work for the *Detect Target* function if the circle is carefully cut.

5 TRAINING THE REALTIME VISION SYSTEM

5.1 INTRODUCTION TO TRAINING THE VISION SYSTEM

Before you are ready to use the Realtime Vision System, you must train it to distinguish the items of interest, for example, between good fruit and under-ripe fruit, between product and foreign material, between one object and another, or a combination of those classes. You will need to have representative samples available for each of the classes. Before proceeding, you should perform a *White Reference Calibration* (accessed via the *Camera Setup* screen). Then, go back to the main screen, click ≡ *Main Menu*, and then *Training*.



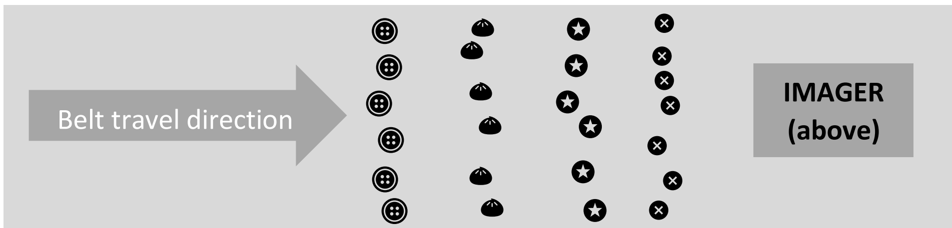
5.2 TRAINING: STEP-BY-STEP

5.2.1 CREATING A NEW CUBE

To the right of the screen is the *Datacubes* panel. In hyperspectral imaging, a *datacube* contains all the information that is acquired in a scan (spatial and spectral information for each pixel). Create a new cube by clicking the ⊕ *Add datacube* button. This is a placeholder for the cube that you will record next.

5.2.1.1 Preparing the Training Set

Set down a variety of reference objects on the belt in a cross-track configuration in preparation for a scan that you will use to train the system. Since you can use multiple cubes for training, it is not necessary that all the samples are present in a single scene. In fact, it might be useful to record a separate cube for each category or class of samples.



5.2.1.2 Acquire a Datacube

Click ● **Start Recording**. Note that the camera will not start recording until the encoder detects belt movement. Start the belt and let it run until all rows of objects have been scanned by the camera. You will see the objects appear in the *Scan feed* as this happens.

Stop the belt. Stopping the belt will halt the recording but you must also click ■ **Stop Recording** to proceed with the remainder of the training process. You have now acquired a *datacube* and are ready to start identifying various objects.

> **Note**: You may acquire several *datacubes* to train a model. To acquire another *datacube* click ⊕ (*Add datacube)* and repeat the scan acquisition steps above. You may also load a previously acquired data cube from disk by clicking 🗀 (*Load cube from disk)*. If the loaded data came from another imager, a message will inform you that the program is interpolating the data to match the wavelength calibration of the current system's imager.

> **Hint**: The left panel contains image visualization tools. These settings do not affect the data; they simply modify how the image is rendered for your convenience. The overlay opacity refers to the areas of the image highlighted with the various selection tools. A value of less than 100 will make the selected areas semi-transparent, allowing you to still see the objects below your selections.

5.2.2 Creating Classes

Classes represent the different categories of objects that the system is trained to recognize. The user creates classes by labeling regions within one or more datacubes.

To create a class, click the ⊕ (*Add Sample Area)* button. A new class will appear in the panel. On the right of that new class, click ≡✎ (*Edit Area Label)* to rename the class to represent the category. Click OK.

Then, click the colored square on the left of the class row to change the color associated with this class. The next step is to use one of many tools to select the pixels that belong to that class.

If you intend to use *Pixel* mode (opposed to the *Object* mode), the conveyor belt must be trained as a class. See Section 6 for more information. In the *Selection Toolbar* below the scan, click the (*Select pixels by drawing freehand)* tool and change the Brush size to 10 pixels. Then draw lines over several large areas of the conveyor belt, <u>avoiding the objects on the belt</u>, but including some of all parts of the belt (polished, scuffed, dirty, both edges, etc.) Finally, ensure that your training selection spans the full width of the belt and that it includes the belt's seam. You could also use the (*Select pixels with a rectangle)* as an alternative.

Now click (*Add Sample Area)* button again to add another class. Rename it to something representative and pick the color of your choice to represent the first type of objects you will train the system to identify. The *(Select contiguous pixels)* tool tends to be quite useful for this purpose. Click *(Select contiguous pixels)* and then click near the center of one of the objects of interest. The tool will automatically select contiguous pixels that are spectrally similar to the pixel you picked. You may use the *Tolerance* slider next to the tool to increase or decrease the extent of contiguous pixels. This tool updates the extent in real-time so you can see the results as you move the slider. **When you are finished, click the tool button again (or any other tool in the toolbar) to finalize the selection.**

> **Note**: The (*Select pixels across the entire image*) tool operates in a similar manner to the *(Select contiguous pixels)* tool but doesn't require the selected pixels to be contiguous. This tool also has a *Tolerance* slider and will similarly only finalize the selection after clicking another this tool button or any other tool button.

There is a range of tools you may use to select pixels in the scan, which are listed in the table below. Experiment with each tool to see which ones may be most useful to select the appropriate pixels. At any time, you may click *Undo* to reverse an operation.

	Selection Tools
	View the entire image
	Zoom in
	Zoom out
	Pan
	Undo
	Redo
	Send the current selection to the trash bin
	Send all selections to the trash bin
	Expand the current selection around the edges
	Contract the current selection around the edges
	Invert the selection
	Exclude the center of a selection, retaining only the border
	Freehand pixel selection (adjust the brush stroke with the BRUSH PX slider to the right)

	Freehand erase selected pixels (adjust the brush stroke with the BRUSH PX slider to the right)
	Rectangular selection tool
	"Magic wand" selection tool selects contiguous spectrally similar pixels. The tool's sensitivity (to spectral similarity) can be adjusted with the TOLERANCE slider to the right
	Similar to the "magic wand" tool above but selects *all* spectrally similar pixels in the scan, whether they are contiguous or not
	Inspect the spectrum at the cursor location

You may add as many classes as you need. In the example above you would create a class for each of the objects you originally scanned: , , , and , in addition to the conveyor belt. Again, you only need to train the belt as a class if you are using *Pixel Classification* mode instead of *Object* mode.

At any time, you may go back and select additional areas for any class by clicking/highlighting that class in the *Sample Areas* panel. Whichever class is highlighted will be the one you are actively working on. Alternate clicks on the class name will activate (highlight) and deactivate that class.

Repeat the above steps until you have acquired several thousand pixels for each class.

5.2.3 TRAINING TIPS:

Make sure that your training areas span the full range of variability of the objects you are training. For example, if you are training nuts and some nuts are naturally lighter or darker than others, make sure you have some of the lightest, some of the darkest, and some of the middle range included in the training set.

Train each class across the entire belt width. In other words, do not put all "A" objects on one side of the belt and "B" objects on the other for training purposes.

Train every part of the objects (center *and* edges), while being careful not to include pixels that don't belong. This is especially important for non-flat objects that cast shadows or reflect light differently at the sides compared to the center.

Shadows should be trained as belonging to the belt class.

It may be possible to streamline the training process by selecting the entire belt with one of the magic wand tools and then inverting the selection to obtain the objects of interest. However, be careful to only train the items you intend to train, excluding dirty belt spots, broken product pieces, shadows, etc. The *Dilate* and *Erode* functions are useful for controlling the selected areas in this case.

5.2.4 SELECTING A MODEL.

Once you have finished creating and labeling classes in the datacube(s), you can train and save a model. A model contains all the data and analytical steps the software needs to accomplish the required tasks. You may train the system to accomplish different tasks, thereby creating different models that can be saved and recalled whenever a specific task is required. Click the (*Model Name*) button to bring up the model selection window, which has descriptions of all the models. The *PLS-DA Classifier* is a good starting point for classification problems, and the *Partial Least Squares Regressor* is a good starting point for regression problems. Both are simpler and faster algorithms. If the performance is not adequate, experiment with other models.

5.2.5 Model Parameters

You may modify the parameters used by the model algorithm by clicking *Parameters* on the *Model* toolbar. The *Label* and *Description* fields are available for user notes, which can be useful when evaluating different models and parameters. For information on how each parameter impacts the results and speed, hover the mouse over the parameters' up/down adjustment arrows.

5.2.6 Training and Saving the Model

Click *Train and Save* to train and save the model. First supply a name and file location for the model, then click OK. RVS will then train a model based on the provided data, and save it to file, which may take a minute. When it is completed, a window will pop up with information regarding the model's performance with details that depend on the chosen model. In the *Cross-validation confusion matrix*, scores tending towards 1.00 on the diagonal, and tending towards 0.00 everywhere else indicate that the model is likely to perform as expected. A graphical confusion matrix on the right provides a simple at-a-glance check of the model's performance.

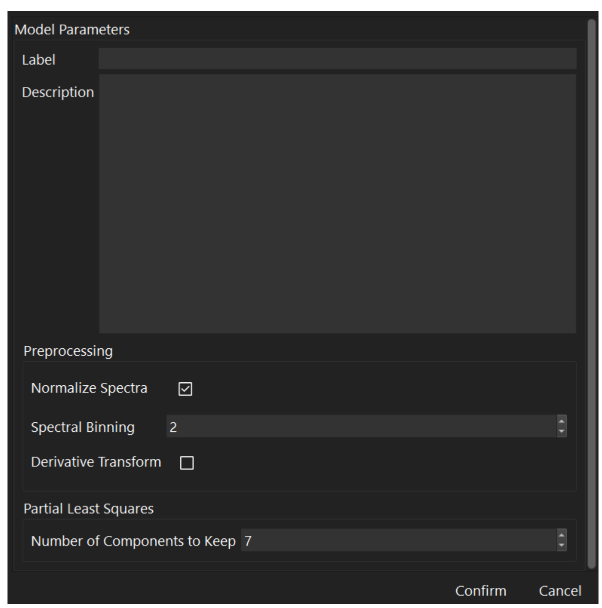
Close the report to continue.

5.3 Exiting the Training Screen

You may now exit the Training screen using the ← *(Back)* at the top left of your screen. The system will prompt you to confirm that you have saved your model. Click Exit to proceed.

6 Object Detection

The Realtime Vision Software can be used in two different units of classification, *pixels* or *objects*. In *Pixel* mode, each pixel is classified individually. In *Object* mode, objects are first identified as clusters of contiguous pixels, then each cluster is assigned a class (or average regression value).



> **Note**: Switching between Pixel mode and Object mode is done in the *Settings* window, which is reached by selecting *Settings* from the Menu. The Settings window is described in detail in chapter 8.1.1.

To use the *Object* mode, you must configure the object detection settings in the *Object Detection* screen. This procedure is explained in the next section.

6.1 Configuring Object Detection

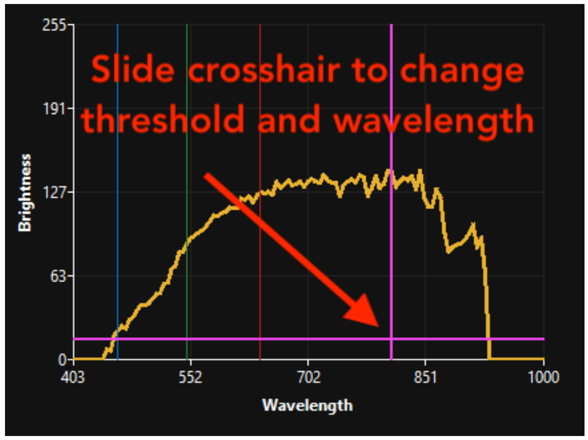
Two criteria are used to define objects: brightness at a user-defined wavelength, and number of contiguous pixels. Once a group of pixels meets the brightness threshold and user-defined size range, it is considered an object and RVS assigns it a class (or average regression value). The brightness threshold can be a lower threshold, if the objects are brighter than the belt (most common), or an upper threshold, if the objects are darker than the belt. The procedure is described below.

1. To begin, access the *Object Detection* screen, via the *Main Menu*. Place objects on the belt, click *Record* and start the belt, stopping both the belt and the recording when the objects have passed under the imager.

   Note: it is also possible to load a pre-recorded datacube into the Object Detection screen. That datacube should have been acquired on the same conveyor belt and properly normalized to reflectance. Whenever possible, it is best to scan new objects.

2. Check the appropriate box: Objects are *Brighter than threshold* or *Darker than threshold*.
3. Alternately click on an object and on the belt while observing the graph in the top left panel. Your goal is to determine a point on that spectral plot that falls clearly <u>between</u> the objects' spectrum and the belt's spectrum.
4. Once you've identified a suitable wavelength and threshold, click that location in the plot to set them. You may also use the sliders in the top right corner of the screen to move the crosshairs in the plot. You will know when a suitable wavelength and threshold have been established when all the objects are overlaid in color and the belt is not.
5. If you are not successful, remember that you also must set minimum and maximum object sizes (on lower right side of the screen). The object size is measured in pixels. A minimum object size can be useful to avoid confusing small debris particles for objects. A maximum object size can also help exclude features that are clearly not objects of interest.

The plot below shows the threshold set below the object brightness (yellow), above the belt brightness (not shown), and at ~800 nm.



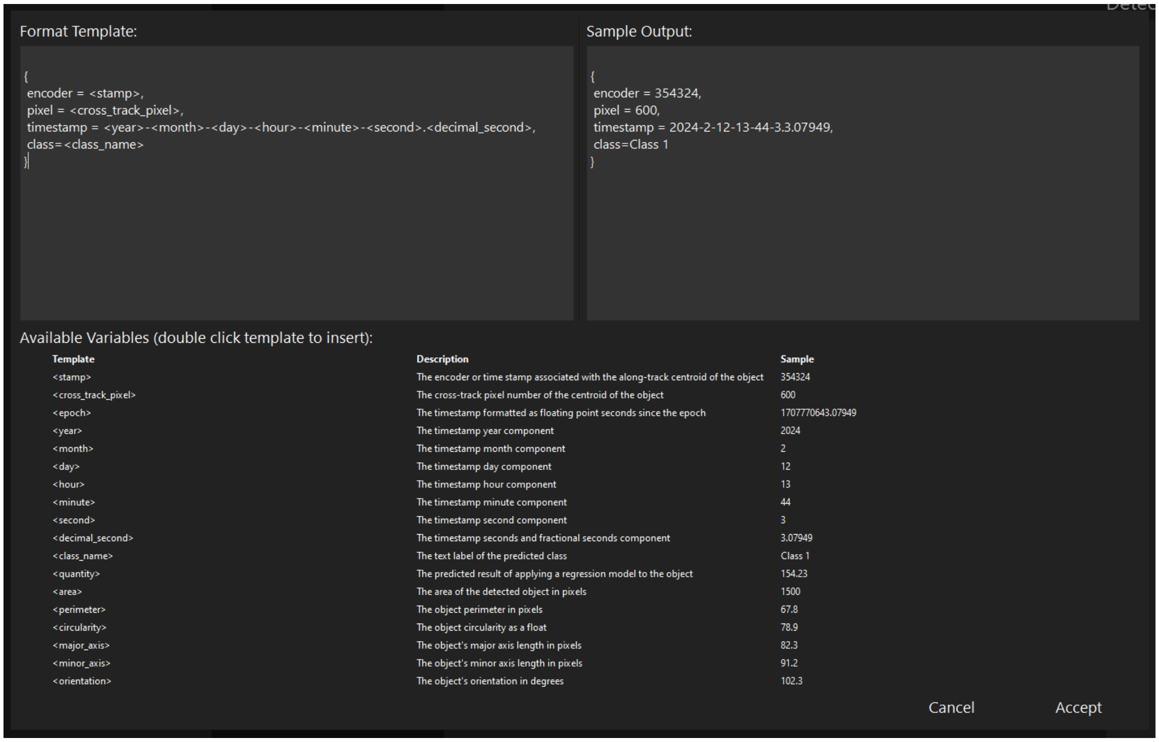
> **Hint**: Use the visualization tools below the spectral plot to help you clearly discern objects from the belt, as well as the selected pixels. Contrast enhancement is often a very useful tool.

7 CONFIGURING THE OUTPUT (RVS *AUTOMATE* ONLY)

When using RVS with Objects as the Classification Unit, the software can be configured to output the classification or regression results to a socket on the ethernet port in formats determined by the user. To set up the output format, go to the Settings screen, then click the Configure Object Output Format.

> **Note**: If this setting is grayed out, it is because the software is configured for Pixel mode instead of Object mode.

In the resulting screen, type the desired formatting characters/words in the Format Template box and double-click one or more of the Available Variables to insert it into the Template box.



In the example below, the system will output everything between the braces (including the braces) for each object detected.

```
{
encoder = <stamp>,
pixel = <cross_track_pixel>,
timestamp = <year>-<month>-<day>-<hour>-<minute>-<second>.<decimal_second>,
class=<class_name>
}
```

Here is a simpler example that uses commas as the delimiter between fields, and a semi-colon as the delimiter between objects.

```
<stamp>, <cross_track_pixel>, <class_name>;
```

8 CONFIGURING AND USING THE IMAGE OUTPUT (OPTIONAL)

RVS *Automate* can optionally be configured to output a classified image to an HTTP port to be used by other code/software.

> **Note**: This feature is computationally intensive and we recommend using object detection and the Output Socket Server when possible, instead of this feature.

8.1 Setting Up the Image Ouput

The feature can be accessed *via Main Menu > Settings > Ouputs* tab > *HTTP Server* and *Configure Image Format*. *This feature is only available when running in *Pixel* mode (*Classification Unit: Pixels*). Under *HTTP Server*, designate a *Port* (for example 3359), and then click *Apply*.

Under the HTTP Server, click *Configure Image Format.* A sub-window will open, and number of configuration options are available:

1. *Lines per Image* is the height of each image (the width of each image is equal to the imager spatial resolution)
2. *Overlap Lines* is the number of lines that are repeated from the end of one image to the beginning of the next image. This may be useful to ensure that each object can be detected in full, in at least one image. Choose a number of overlap lines that corresponds to at least the size of your objects (in pixels).
3. *History Length* is the number of png images kept in active memory.

When finished, click *Accept* and close the *Settings* window.

8.2 Viewing the Image Output

While running the pixel classifier, open a browser window and navigate to one of the following addresses:

localhost:3359/model_info: ("3359" is the example port, you may have chosen another port, modify the web address accordingly). This shows the classification legend, including class name, color, and integer code used in the PNG image for each of those classes. An example is shown below:


```
{
  "classes": [
    {
      "class": {
        "class_name": "PET",
        "color": "#c62828",
        "integer_code": 1
      }
    },
    {
      "class": {
        "class_name": "HDPE",
        "color": "#f9a825",
        "integer_code": 2
      }
    },
    {
      "class": {
```

```
                "class_name": "BELT",
                "color": "#558b2f",
                "integer_code": 3
            }
        }
    ],
    "filename": "C:/Users/user/test.rvsmodel"
}
```


localhost:3359/latest: This window shows the latest PNG image that was produced. It does not auto refresh.

localhost:3359/slideshow: This window auto refreshes about every second.

localhost:3359/image_history/image_number: Here, *image_number* is the desired image in order, */image_history/2* is the image collected 2 images ago, and */image_history/0* is the same as */latest*

> **Note**: In the PNG file metadata, the integer code, and color associated with each of those codes, is included. This is standard PNG formatting. Also included as supplemental metadata, are the encoder counts corresponding to the first and last line of the PNG image as *FirstStamp* and *LastStamp*.

9 Using the Realtime Vision System

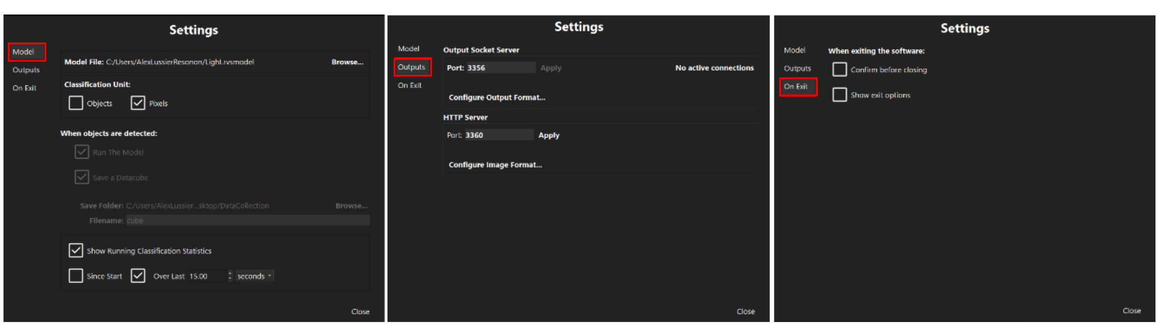
Standard operation of the Vision System occurs in the *Main* screen. If you are on another screen, you can always return to it by using the ← *(Back)* at the top left of whichever sub-screen you are on.

9.1 RVS Running Modes

RVS can be run in different modes, and changing modes can be done by accessing the ⚙ *Settings* window.

9.1.1 RVS Settings Window

The *Settings* window includes several settings, under three different tabs (*Model*, *Outputs*, & *On Exit*) which show up in the top left of the window. This window allow users to choose how to use RVS.



9.1.1.1 Model Tab

9.1.1.1.1 Model File:

Use the *Browse* button to load a previously saved classification or regression model.

9.1.1.1.2 Classification Unit:

You may choose to run RVS in *Object detection* mode, or in *Pixel classifier* mode.

Objects: In object detection mode, RVS groups pixels into objects, and outputs classification or regression results at the object level. When an object is detected, a picture of it shows on the right-hand panel of the Main Screen along with its class or average regression value, along with its detection date, time, and location on the belt.

> **Note**: In order to run in object detection mode, you must configure the object detection in *Object Detection* settings. This is covered in a previous section of this manual.

Pixels: In Pixel Classifier mode, RVS assigns a class to each individual pixel, without grouping contiguous pixels into objects, based on the classes that you trained it to recognize. To run in this mode, you should have created a conveyor belt class during training. It is common to assign it a black or dark gray classification color. If you do not train the system to recognize the belt as a distinct class, belt pixels will be assigned to one of your classes of interest.

9.1.1.1.3 When Objects Are Detected:

The options under *When objects are detected* are only available when using object classification. Two options are available:

Run the Model: RVS will run the model that you've trained in real-time.

Save a Datacube: Whether you are running a model or not, you can save a datacube, along with a jpg image of the detected object, in a location of your choice. This feature is extremely useful to collect large quantities of data, quickly and efficiently.

9.1.1.1.4 Statistics

Check the *Show Running Classification Statistics* if you wish to observe a running tally of the percentages of each class of product detected on the belt. You may have the software compute these statistics over the entire running time (total statistics), or over a user defined interval (latest statistics).

9.1.1.2 Outputs Tab

RVS-Automate provides a mechanism for external applications to receive real time data (object class, location, time of detection, size, etc.) about each object detected by RVS. To facilitate this, RVS can run a TCP server on the port configured in the "Output Socket Server" field. External client applications (for example, downstream computers, PLCs, or process control equipment) can connect to this server using a standard TCP/IP connection as client devices to receive messages each time an object is detected. This is a simple one-way communication protocol. RVS will accept any incoming connections and broadcast its output to those clients. Any data sent to RVS by client applications will be ignored and discarded. A single message is broadcast for each object detected.

9.1.1.2.1 Output Socket Server

User-defined port. The default is 3356.

9.1.1.2.2 Configure Output Format…

This option pertains to the *Automate* version of RVS. It will not show up if using RVS *Acquire* or RVS *Analyze*. Clicking on this option opens a window allowing the user to configure the output in a way that is most convenient for downstream use. The message format is completely user-configurable using the template-language described in Chapter 7 of this manual, and defaults to a JSON formatted string.

9.1.1.2.3 HTTP Server

The user may set up a port to send object images on an http server in real-time. This feature is computationally costly and, as a general rule, we recommend sending fully processed RVS output over the Output Socket Server instead.

9.1.1.2.4 Additional Resources

Python computer code examples for reading the socket server and web server outputs can be found in your installation folder. If you chose the default installation location, this will be under C:\Program Files\RVS\examples.

9.1.1.3 On Exit Tab

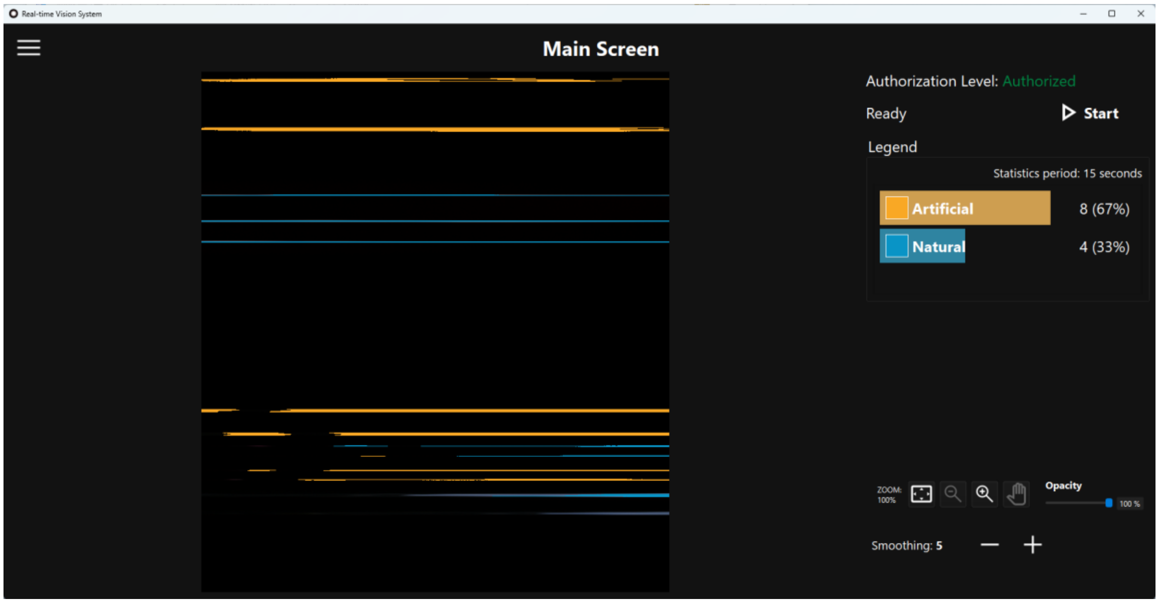
9.1.1.3.1 When Exiting the software:

RVS, by default, asks users to confirm that they want to exit the software, to avoid accidentally closing the software during critical operation. Users may check either box to bypass the exit confirmation steps.

9.2 RVS Main Screen

The Main Screen is active upon launching RVS. The latest classification or regression model used will be automatically uploaded. It is recommended to check the response correction in the *Camera Setup* screen, but it is possible to click ▶ *Start* (top right of the main screen) to begin analyzing product in real-time immediately. Unless working in *encoder-less* mode, the system must also detect belt movement via the encoder to begin classifying

If working in Pixel mode, a Smoothing filter can be applied to the scan feed by clicking the +/- *Result Smoothing* icons in the bottom right panel. Smoothing effectively removes the smallest pixel clusters from the scan feed. A larger smoothing *window* size removes larger isolated groups of pixels. A setting of zero means that no smoothing is being performed on the data.



Main screen

10 Using RVS to Collect Datacubes

RVS can be used to quickly and efficiently collect large quantities of datacubes, to use in Spectronon or any other ENVI-compatible software. To enable this functionality, go to the *Settings* screen, under the *Model* tab, make sure *Object* mode is enabled, uncheck *Run the Model* box, check the *Save a Datacube* box, browse for a folder where you want to save the data, and choose a *Filename base*. Then hit close. When the system is run from the main screen, datacubes will be created and saved from all detected objects, along with a jpg image of each object. As noted earlier, the object in the datacube will be surrounded by zero-value pixels to make the image rectangular. Please remember that you must set appropriate parameters in the *Object Detection* screen for RVS to properly isolate objects. You may access this screen from the Main Screen's main menu.

11 Quick Step-by-Step Reference Guide

Once you have gone through the setup process several times, you are likely to remember how to accomplish each step, but it is easy to forget to perform one of the steps. You may use this Step-by-Step Quick Reference Guide to ensure the system is set up properly. Refer to the main body of this manual if you have forgotten details of how to perform a specific step.

- ✓ Check components.
  - Check that the computer is connected to a power source (standard AC outlet) and to the network (if applicable) via the correct ethernet port (labeled) on the computer.
  - Check that the imager is properly connected to the computer, and a power source if applicable (Pika IR, Pika IR+, and Pika L Gig-E)

  - Check that the encoder is connected to one of the computer USB ports with the supplied QSB-D model USB adapter.
  - Check that the light source is plugged in and turned on (15 minutes recommended to thermally stabilize halogen light sources).
- ✓ Launch the software.
- ✓ If any components have been moved or modified, go through the entire Camera Setup procedure.
  - Focus the imager.
  - Set the *Integration Time* (use the Automatic Integration Time).
  - Set the *Target Framerate* (use the Automatic Framerate).
  - Perform the *Dark Reference Calibration*.
  - Perform the *White Reference Calibration*.
  - If appropriate, reset the *Master White Reference*.
  - Briefly run the belt to make sure that the encoder counts are increasing. If not, go to the *Settings* screen to check (or uncheck) the *Reverse Direction* box for the encoder.
  - Check the images' aspect ratio. If it is incorrect, fix it by adjusting the *Encoder Counts per Frame* in the *Encoder Setup* screen.
  - Exit the *Camera Setup* screen and begin using the system.
- ✓ If you need to train the system to perform a new classification, perform a W*hite Reference Calibration* and then go through the training procedure using the *Training* screen.
  - Add a new datacube.
  - Start the camera, run the belt, and acquire a scan (datacube) of your training objects.
  - Create object classes and select areas of the scan for each class.
  - *Train and Save* the model.
  - Exit the *Training* screen.
  - Configure Pixel or Object mode in *Settings* and set up *Object Detection* parameters if applicable.
  - Begin using the system.
- ✓ Once the system is fully focused, calibrated, and trained, perform a *White Reference Calibration* and start using the system by clicking ▶*start* on the top right of the main screen and turning on the belt.

12 Using Configuration Files

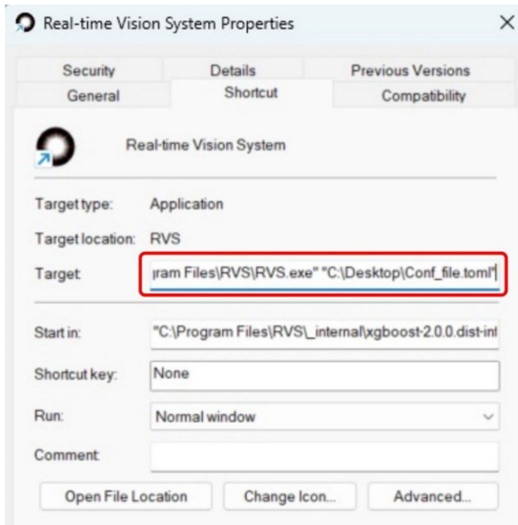
The behavior of RVS can be configured for specific scenarios by using a configuration file. Multiple files can exist, which allows the user to select which specific configuration to use when running RVS. This can be useful for using RVS in demonstrations, without an encoder, or with a simulated camera instead of an actual imager.

12.1 Creating a Configuration File

A configuration file is an ordinary text file with a *.toml* extension. It can be placed anywhere on the computer's file structure. Files can be created and edited using Notepad or other text editors. After you've created a file, change the *.txt* extension to *.toml*. An example name and path might look like: *c:\\RVS Configurations\\demo_mode.toml*

12.2 Launching RVS With a Configuration File

First, locate or create a shortcut to the RVS executable (an RVS icon on your desktop, or on your *quick launch* bar). Then right-click on the shortcut and select Properties. In the Target field, insert the cursor to the right side of the text field, past the quotation mark. Type a space and then the path to the .toml file. Press OK. An example is shown below.



You can create multiple shortcuts, each with their own configuration file path. It is helpful to name each shortcut to represent its configuration.

12.3 Configuration File Options

The following are some useful options for the configuration file. Multiple options can be included in the same configuration file.

12.3.1 Free Run (No Encoder)

RVS can be operated without an encoder for demonstration purposes or for laboratory use. In this case, the aspect ratio of the images can only be adjusted with the imager framerate or the conveyor belt speed. To use this mode, include the following line in the configuration file:

use_encoder = false

12.3.2 Simulated Imager

RVS can use a pre-recorded datacube to simulate an imager when an actual imager is not practical, usually for demonstration purposes or evaluating the feasibility of a problem. To do this, include a line similar to the one below:

simulated_camera_file = “C:\\datacubes\\almonds.bip”

Where *C:\\datacubes\\almonds.bip* is the path to your datacube. Include the quotation marks on both ends. As always, the corresponding header file to the datacube must be in the same folder.

12.3.3 Full Screen

RVS can be launched in full screen with the following addition to the configuration field:

fullscreen = true

12.3.4 Start Authorized

RVS can be launched without need for authorization to access all the functionality. It can be de-authorized after launch, if desired.

start_authorized = true

12.3.5 Check For Updates

RVS automatically checks for more recent versions of the software and notifies the user. This is only a notification, RVS will never update automatically. Nonetheless, this feature can be disabled by including the following line in the configuration file:

Allow_update_checks = false

13 Glossary of Terminology

Class: In Realtime Vision System, a *class* is a group of spectrally similar objects, or parts of objects, that we wish to differentiate from the rest. If you simply want the Vision System to identify objects as they run down the conveyor belt, you will create two classes (one for the objects, and another for the belt). If you wish the system to differentiate good objects from bad objects, you will create three classes (one for good objects, one for bad objects, and one for the belt,). If you wish the system to differentiate between "good" parts of an object from "bad" parts of an object you will again create three classes (one for the good parts, one for the bad parts, and one for the belt).

Dark Reference calibration: Calibration that is done to compensate for the sensor's dark current.

Datacube: The entire dataset associated with a scan. A hyperspectral image has two physical dimensions but also a third spectral dimension. The data set must keep track of intensity as a function of x, y, and w. Hence the designation data*cube.*

Encoder: Device used to keep track of conveyor belt movement, much like the odometer in your car.

f-1 score: A metric to rate a classification model's quality, or ability to perform the classification task. Mathematically: *f-1 = (2*Precision*Recall)/(Precision+Recall)*

Integration time: This is the imager's dwell time to acquire each line in a scan. It is exactly like the exposure time on a traditional camera. Longer integration times allow the imager to capture more light. Too long of a dwell time will saturate pixels and/or lead to motion blur.

Model: In Realtime Vision System, a model consists of all the information acquired to perform a specific classification task. It includes the sample areas designated by the user as representative of the various classes, and the mathematical algorithm applied to those classes to sort whether a subsequently acquired pixel belongs to one class or another, based on its spectral makeup.

Precision: Indicates a model's success rate as to whether the pixels it identified as belonging to a class *indeed* belong to that class. Mathematically: *TruePositives / (TruePositives + FalsePositives)*.

Recall: Indicates a model's ability to correctly identify all pixels corresponding to a given class. A score of 1.00 indicates the model correctly identified 100% of the pixels it was aiming to identify. Mathematically: *TruePositives / (TruePositives + False Negatives)*.

Sample area: In Realtime Vision System, this refers to areas of a scan selected by the user as belonging to a chosen class for the purpose of training the system.

Scan: The process of acquiring a datacube.

Scan feed: The on-screen live image of objects travelling down the belt, which can be an RGB visualization of the data (regular image) or a color-coded classification of the objects travelling down the belt.

Sensor Map: Two-dimensional live representation of what the camera sensor is seeing. The horizontal axis corresponds to the physical cross-track location in the line scan, and the vertical axis represents the array of wavelengths associated with each of the physical locations in the line scan.

Target Framerate: The number of line images acquired by the imager every second. It is a "target" framerate because the software only retains as many lines as it needs to produce images with the correct aspect ratio.

Waterfall scan feed: A recent history of the imager's linear field of view. The horizontal axis corresponds to the physical cross-track dimension while the vertical axis represents time from *t* = "*a few seconds in the past"* to *t* = "*now"*.

White Reference Calibration: Process to acquire a reference datacube used to correct all subsequent datacubes with respect to instrument-sensor-response and spatially nonuniform illumination effects. This should be redone regularly to account for possible lighting fluctuations.

White reference material: High diffuse reflectance material such as Spectralon®, Fluorilon®, or sheet of white Teflon® that is used to calibrate the imager response.

14 Performance & Diagnostics

14.1 System Speed & Performance

The speed at which RVS can perform classification and regression tasks depends on a number of factors.

14.1.1 Illumination

Insufficient illumination can force longer integration times, thereby limiting the frame rate at which the system can perform. Solution: Provide more illumination.

14.1.2 Data Transfer

Every imager has a maximum achievable frame rate (regardless of illumination). Potential solutions: Experiment with spectral or spatial binning. If your task does not require the instrument's full resolution, binning reduces the data transfer and processing volume, potentially enabling faster operation. The Pika L-F is capable of higher framerates in part because it captures 8-bit data instead of 16-bit data for the Pika L. If your application does not require the dynamic range of the Pika L, the Pika L-F may be adequate.

14.1.3 Model Complexity

Overly complex models can overwhelm the computer's CPU. Possible solutions:

- Experiment with other models. For example, a logistic regression classifier is simpler and inherently faster than a gradient boosted tree. For some applications, it is adequate and a better choice.
- Reduce the number of *estimators*, *branches*, *boosting rounds*, *tree depth*, or *components to keep* in your model's parameters.
- Experiment with spectral binning. If your application does not require the instrument's full spectral resolution, binning can speed up the model (for VNIR imagers).

14.1.4 Other Processes Running in Parallel

Typically, a dedicated computer is used for RVS. Nonetheless, the use of the http server, for example, utilizes substantial computational power and can limit the computer's ability to keep up with the classification or regression task. We recommend using the Output Socket Server when possible, which only broadcasts a small quantity of processed, object specific data.

14.1.5 Diagnostics (Benchmark)

If model complexity is suspected of being a limiting factor, the Benchmark Model may help. (*It can only be used in *Pixel* mode.) The tool is found under *Main Menu > Benchmark Model*. It is used to determine if the computer can execute the current model fast enough for continuous classification. Keep in mind that this *only* benchmarks the model, not the entire system. In reality, RVS also needs to collect the data, run the encoder, perhaps smooth the data, as well as running the GUI, the Output Socket, the http server, and any other tasks being handled by the computer.

The benchmark tool feeds the model random simulated data as fast as it can generate it. The plotted framerate (in blue) represents the computer's ability to process data using the current model. The blue line moves down if CPU resources are being used by other processes, or even the CPU is being throttled down by the operating system because it is getting too hot (common on laptops, less on desktops). The red line is the imager's current frame rate.

If the blue line is consistently over the red line, you may assume that the computer can run the model faster than the camera acquires data. Again, this tool only tests only the computer's ability to run the model. Other processes running in parallel will utilize computational power, affecting the computer's ability to keep up.

15 FAQs

1. **Can I view real-time statistics of what is detected on the belt?** Yes, that feature can be activated under ≡ *Main Menu >* ⚙ *Settings > Model Tab* by clicking the *Show Running Classification Statistic*s box.
2. **Can I avoid the confirmation dialogue when exiting RVS?** Yes. Please go to ≡ *Main Menu >* ⚙ *Settings > On Exit Tab*, and check/uncheck the "When exiting the software" options.
3. **The Live Scan Feed on the main screen disappeared.** It is likely that your computer is not able to keep up with the task at hand. Consult the Performance and Diagnostics section of this manual
4. **How do I get support?** Please contact us at support@resonon.com. Please include details and include your logs, which you may generate a zip file of your logs by going to ≡ Main Menu > 🗎 Logs > 🗃 Zip Log Files.

16 Product Support

You may contact Resonon by phone, email, or via the form on our website:

Phone: 1.406.586.3356
Website: https://resonon.com/support
Email: support@resonon.com or software@resonon.com

If you are experiencing difficulties, we recommend that you send us your logs. To generate logs, please click on ≡ Main Menu > 🗎 Logs > 🗂 Zip Log Files.

17 COPYRIGHT NOTICE

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Resonon welcomes any recommendations regarding this manual. Customer feedback is always welcome as it helps us to continuously improve the quality of our products.

Please contact us at Resonon with any questions or comments. We look forward to hearing from you.