The Material Attribution Database Manager: A Tool for Storage, Interaction and Manipulation of Material Measurement and Attribution Files

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Abstract. The Material Attribution Database Manager, MADM, is a utility developed to support the storage, management, processing, evaluation, and use of a broad range of electro-optical material properties data. MADM fulfills an urgent need on the parts of designers of fully-synthetic simulation targets as well as researchers studying electro-optical signature phenomena. Designed to facilitate the attribution of synthetic targets and scenes with laboratory-measured reflective and emissive properties for radiometric simulations, MADM's browse, search and export capabilities are found in no other material properties database. This paper provides a high-level overview of the tool's architecture, user interface, and workflows to familiarize the reader with the capabilities MADM provides.

1 Introduction

Use of synthetic targets and scenes for radiometric simulations has a number of advantages over traditional methods involving archival image data: First, removal of optical aberrations and sampling effects imposed by the original imaging system invariably introduces unwanted artifacts. Second, features in the archival field may be undesirable and impossible to remove, such as shadows inconsistent with the illumination conditions to be simulated. Third, the "truth" values of parameters to be estimated from the simulated data, such as reflectivity or target size, are known exactly, allowing the performance of processing and estimation algorithms to be quantified [1]. Fourth, because noise from the original detector is permanently a part of archival imagery, only very high-SNR data can be used, limiting simulation scenarios. Finally, noise is represented formally in calculations of information-theoretical limits to parameter estimation, again requiring very high-SNR archival data [1,2] and implying the same limitations.

Developing high-fidelity, radiometrically-accurate simulations with fully-synthetic targets and scenes requires detailed geometries combined with well-characterized material properties, such as reflectivity and bidirectional reflectivity distribution function (BRDF) data. A detailed target can contain tens of unique materials, and complex scenes can contain hundreds of targets. Further detail can be captured in the background of a scene, such as terrain, plants, man-made objects, and other realistic clutter required to test image processing algorithms. Keeping track of lists of materials to properly associate ("attribute") the surfaces of the detailed geometries is a tedious and time-consuming process and managing the support data files required for radiometry engines like DIRSIG can easily lead to errors that result in reduced quality and increased development time. Information on the source and provenance of the material data; processing that has been applied; and consistency across multiple software formats also becomes increasingly challenging to create, track and associate, limiting the ability to relate and track the pedigree of a material.

To solve the issues addressed above and reduce the cost of target design, the Material Attribution Database Manager (MADM) was developed. MADM is a powerful utility that provides database storage of material properties data combined with a user interface that enables browsing, visualization, and data import/export functionality for the database. MADM provides a common, easy-to-use interface that is accessible by diverse users spanning from radiometry and phenomenology experts to skilled graphics artists who together develop high fidelity scenes and targets used in radiometrically-accurate simulations.

MADM's initial development was motivated by the need to organize material data specifically for the DIRSIG radiometry tool; however, the value in addressing a wider range of material management needs soon was identified. In response, MADM development has shifted to incorporate and manage materials at a more generic level. As a result, the utility has become an extensible tool capable of storing, relating, tracking, and processing additional material sources and formats. Because it is designed to be extensible, MADM is a tool under continuous spiral development. The ongoing development activities are aimed at adding features, functionality, and format support based on user feedback.

This paper provides a high-level overview and summary of the MADM architecture, its primary capabilities, and basic workflows promoted by the MADM UI. It is not intended as a comprehensive user manual.

2 Architecture

MADM is a tool developed for a diverse set of users to interact with material attribution information, its related support elements, and processing utilities. It does this by providing a User Interface (UI) that simplifies interaction with a true relational database, so users do not need to be database experts. The UI enables browsing, search, and evaluation of database contents, while providing utilities to import new data and export support files and data for use in simulations and studies.

Figure 2-1 shows a high-level depiction of the MADM architecture with its three core UI components. The Import and Export capabilities are processing activities that manage database I/O, and the figure captures the high level flow each process undergoes during operation. The Browse and Assess capability encapsulate the ability to interact with the existing database contents. Its representation in the figure highlights the key functionality for which the capability is intended. The diagram shows all three of these elements hosted on the MADM UI, which serves as the middleman between the user and the MADM database.

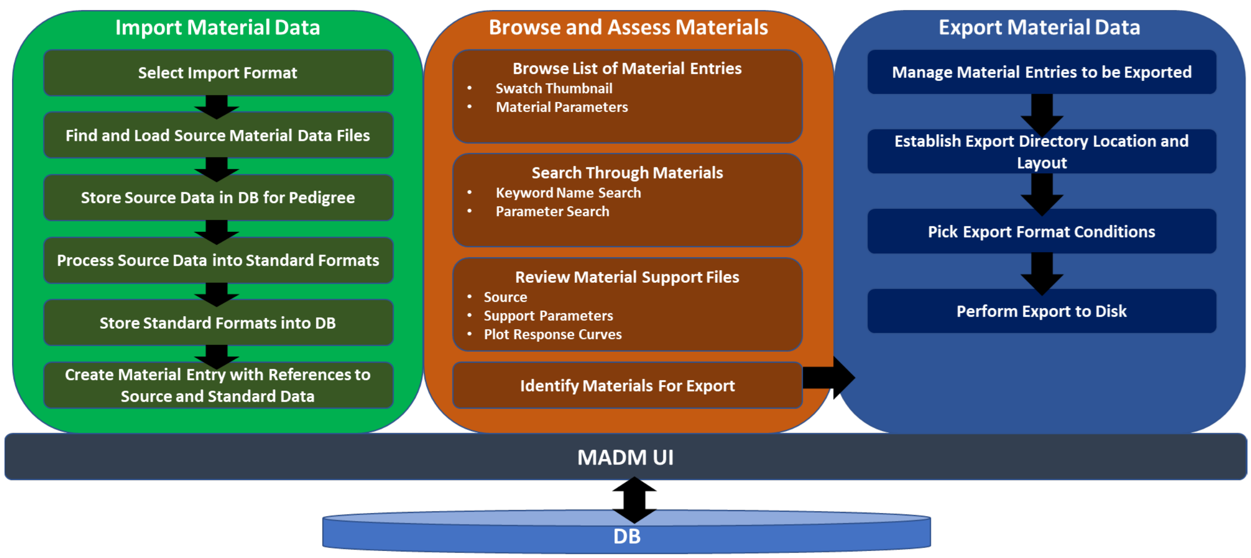

Figure 2-1 High level architecture of the MADM UI and database

2.1 Database Structure

MADM contents are stored in a single MongoDB database. MongoDB provides a flexible dynamic database storage environment that allows for quick expansion given new data elements, efficient storage of subsets, and relational structures for associating common elements to multiple entries. MongoDB is augmented with GridFS, the MongoDB specification for storing and retrieving large files, for storing data files directly in the database.

The MADM database is organized into hierarchical collections, each with a combination of documents containing direct attribution data as well as references to related collections. This organization structure is captured in Figure 2-2.

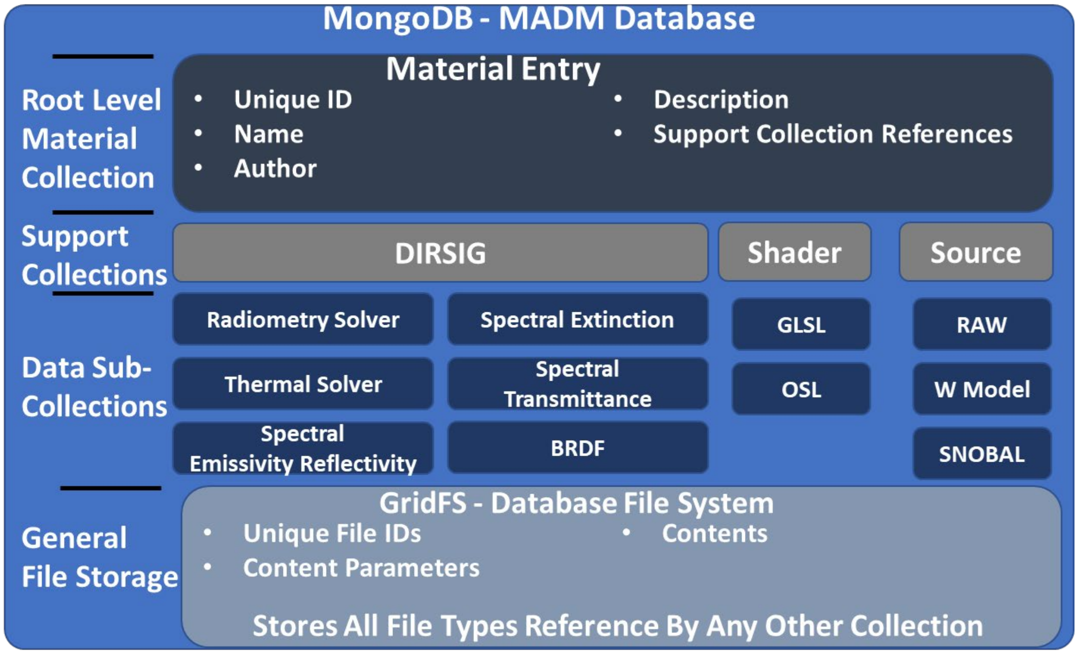

Figure 2-2 MADM database organizational structure

Every item in the MADM database is referenced back to a root material entry. These entries are browsable and searchable to aid in database navigation. Each entry can reference one or many support collections, such as laboratory measurement source data as well as the associated DIRSIG model parameters. Each support collection contains data sub-collections for storing the specifics of that support item.

2.1.1 DIRSIG Support Collection

The DIRSIG support collection consists of many data sub-collections that capture both the properties of the material as well as configuration data to utilize the attribution data in radiance calculations. DIRSIG Data Sub-collections such as the Radiometry and Thermal solvers fall into the configuration category, and they contain only parameterized configuration entries. More extensive data structures, such as the spectral distribution of anisotropic directional hemispherical reflectance responses, can contain tens of thousands of entries and are stored in their original source file format in the GridFS collection. The GridFS entry is then referenced by the relevant data sub-collection.

2.1.2 Shader Support Collection

The Shader support collection, still undergoing development, provides access to descriptions of material properties in formats utilized by popular 3-D graphics artist tools such as Maya, Blender, etc. This collection provides target designers with a way to visually maintain consistency of materials from the design and model development phase through the radiometric simulation process.

2.1.3 Source Support Collection

The Source support collection enables storage of laboratory measurement and modeling data. Import tools provided in the MADM UI allow a user to incorporate raw measurements into the database and process that data to create derivative support collections described in Sections 2.1.1 and 2.1.2. The import process maintains a precise pedigree for raw data by capturing the source, version controlling the processing, and storing with direct relation to the Source any processed Collection products. If any questions or artifacts are identified in simulation results using MADM attributions, MADM itself provides the mechanisms to investigate the data directly through summary statistics and visualizations.

2.1.4 Support Collection Expansion

MongoDB allows for expansion of the database for new Support Collections and Data Sub-collections as they are identified. New collections would be needed, for example, if new shader models are specified or if a new source format is added. With MongoDB, it is only necessary to specify the fields relevant to that entry. This means the database itself allows for new collections to be specified for any material but does not require a process to populate or null-fill material entries that do not use the new collection.

2.2 Interface Layout

The current MADM Graphical User Interface (GUI) is a tab-based UI that organizes and displays a combination of lists of datasets, data fields, reference imagery, and even graphical representations of more complex data elements.

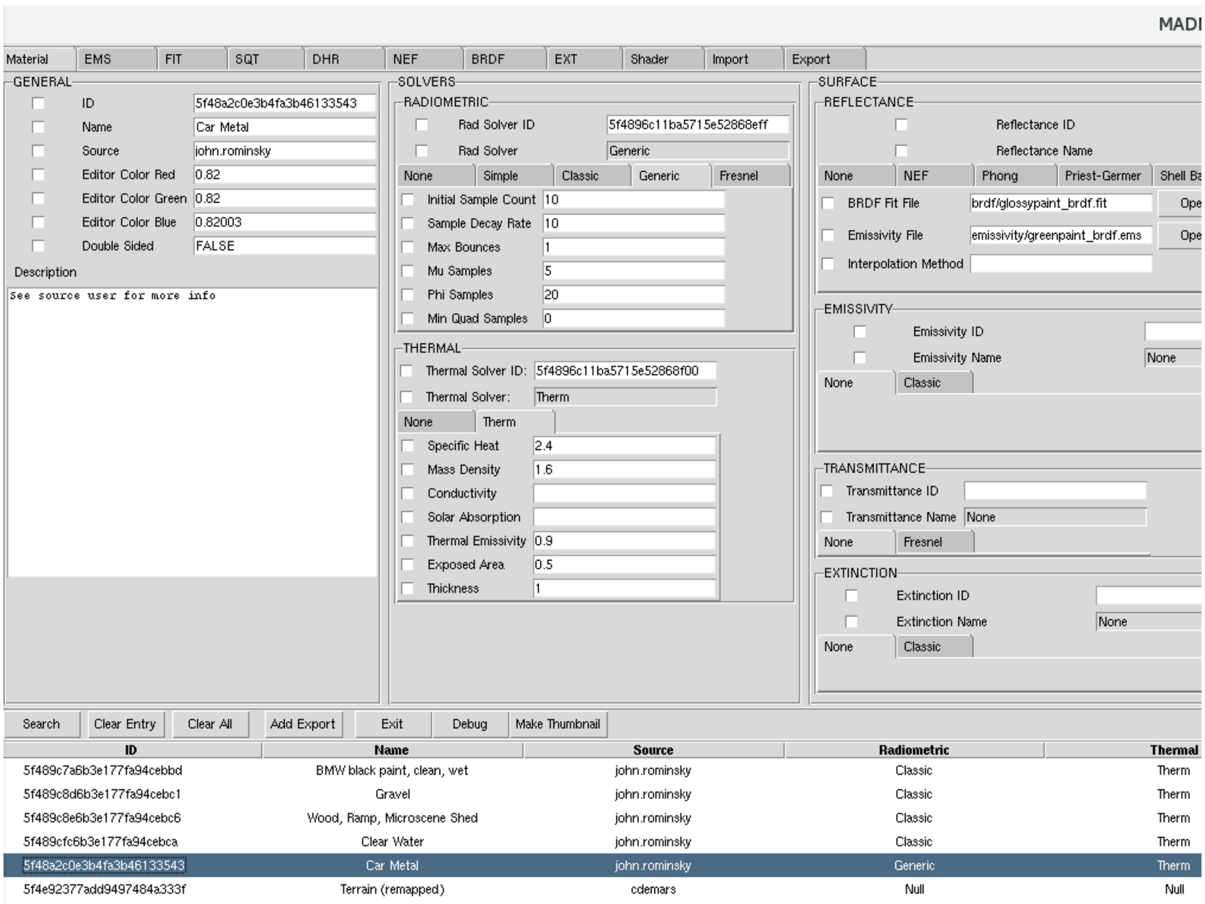

Figure 2-3 A section from MADM's interface for the material tab showing a list of entries at bottom with a selected material populating the data and graphical fields above.

The tab structure can be seen in at the top of Figure 2-3. There are tabs for the three core functions of MADM, the Material tab for browsing, the Import tab for incorporating new data into the database, and the Export Tab for saving database contents out to a file system. At present, there are additional tabs for each of the support file formats recognized by MADM, though these tabs will be consolidated into a single "Files" tab in the next release.

All tabs are organized around a common structure: The top left contains the general information about the current entry displayed, fields to the right contain the technical data associated with the entry, and a table at bottom organizes multiple entries for browsing. If files are referenced in the technical data, adjacent "Open" buttons provide direct access to the specific file's support interface. Supplemental functionality and processing capabilities are accessible in the button bar above the table at bottom.

The material tab, shown in Figure 2-3, conforms to our structure. The core information that defines the material in the database is listed in the top left under the GENERAL frame. The information to the right of the GENERAL frame contains the available DIRSIG entries that define what radiometric solvers are defined for the material and what parameters and attribution files are used to describe the surface properties of the material. Furthest to the right is a thumbnail image of a standardized swatch simulation rendered through DIRSIG. At bottom is a list of all available materials that meet the search criteria. The default search criteria are wide open showing all materials in the database.

2.2.1 Support File Tabs

The support file tabs follow the same structure, as can be seen with the EMS tab shown in Figure 2-4. The support tabs can be reached by clicking on the tab itself or by following a technical data file Open button. Support files often contain complex data that define parametric models or large quantities of measured data that makes little sense when simply viewing the file text. Instead, MADM provides technical fields that summarize the support file extents and key attributes, and where applicable, allows for visualization plots of the complex or large data elements in graphical formats that make the data easier to interact with and consume.

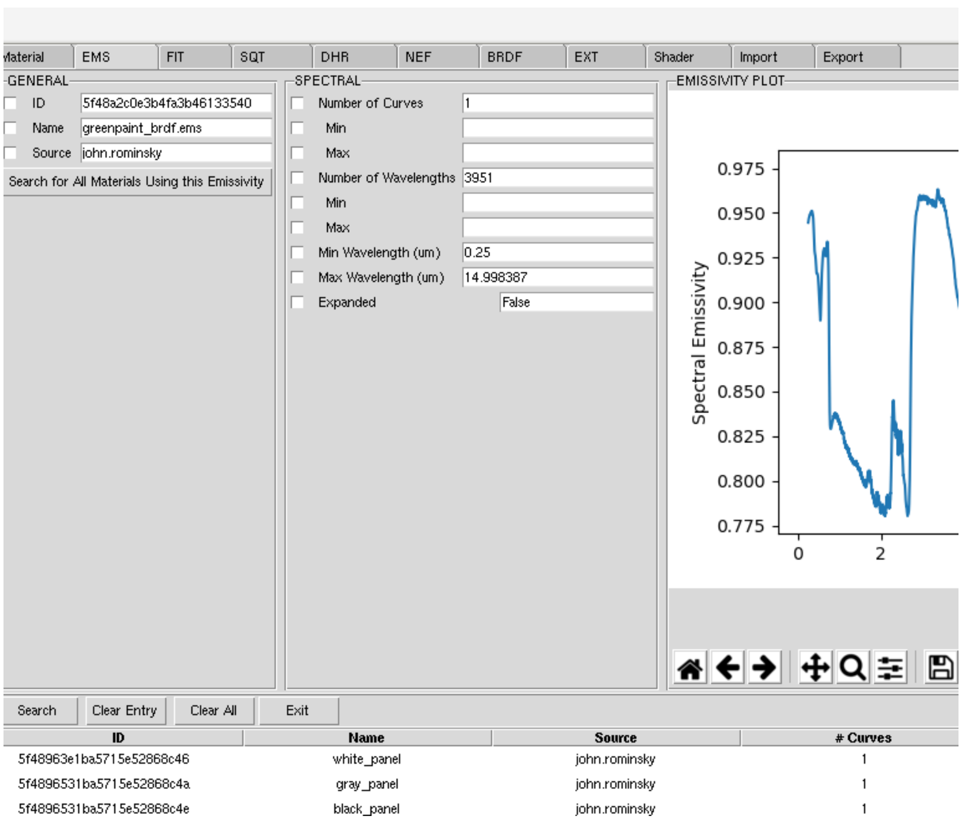

Figure 2-4 A section from MADM's support file tab for the DIRSIG EMS or emissivity file format

2.2.2 Import Tab

The import tab provides an interface for processing new database inputs, including high level data and process status review components. The interface for the DIRSIG material file import is shown in Figure 2-5. The tab provides a compact interface to interact with a material file and its support file paths, such as loading a files contents or modifying the support path defaults. Two text fields are also included: The ENTRY DATA field provides a mechanism to review the raw text from material input entries. The IMPORT LOG field is a running log from the import process giving the user status to monitor import progress and success. The table at bottom provides a convenient mechanism for organizing, interacting with, and displaying multiple material entries contained within the specified material file.

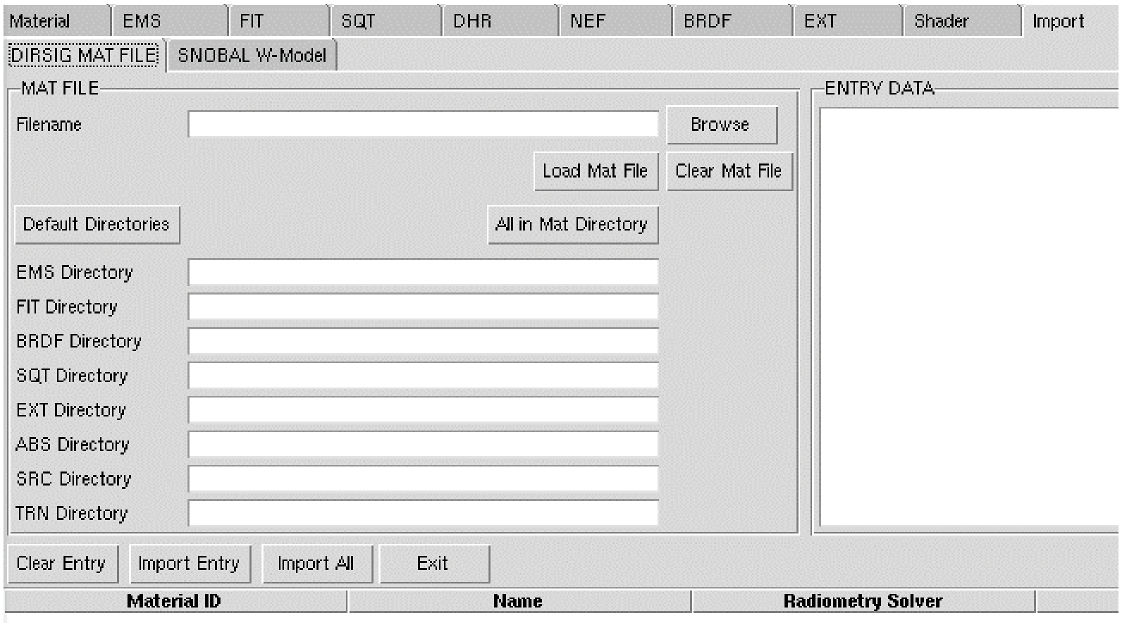

Figure 2-5 A section from MADM's import tab interface used to input new material data into the database.

2.2.3 Export Tab

The export tab provides a processing interface to save database material entries as formatted, simulation-ready files in the desired external location. The export interface is shown in Figure 2-6. The tab provides a compact interface for specifying database material entries, export options, and export formats utilized by the export process. The options, paths, and format controls are listed at top, and the list at bottom displays the database material entries to be exported.

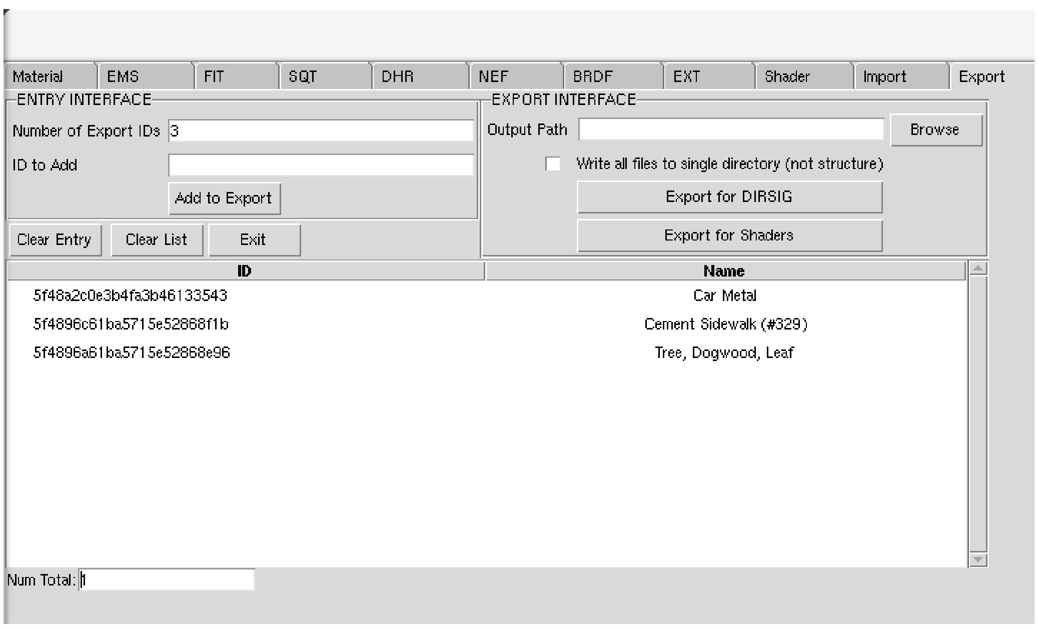

Figure 2-6 MADM's export tab interface used to output database contents to a file system.

2.3 Processing Utilities

In addition to interacting with the database, MADM's UI provides access to processing resources for manipulating the database contents. Here are some examples:

The “Make Thumbnail” button provides access to a standardized DIRSIG simulation. Clicking this button initiates a sequence of processing events that consist of exporting the selected material’s DIRSIG material and attribution files, running the DIRSIG “swatch” simulation, post-processing the output radiance map, and populating the database with a standardized image for future use. An example “thumbnail” is show in Figure 2-7, and makes it easier for a target designer to visually assess material properties. The thumbnail generation process is also useful for verifying that a material can be exported into functional DIRSIG attribution files.

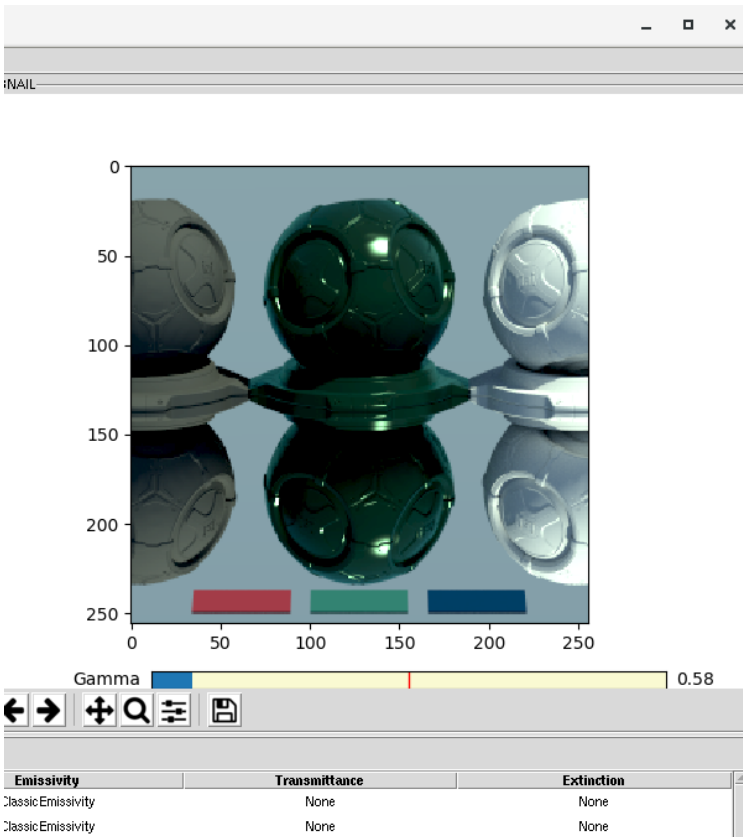

Figure 2-7 MADM UI displaying thumbnail of standardized DIRSIG swatch simulation.

The import tab provides several processing features as well. When importing from a DIRSIG “*.mat” material file, its contents are simply read in and stored in the database. However, when reading in from, e.g., measured goniometer data, the data can be processed into DIRSIG and/or shader files capturing the imported contents. This provides for standardized approaches to transforming data into simulation-ready information.

Processing capabilities under the export tab include the ability to combine multiple material entries into a single DIRSIG *.mat file format and adjustable directory structures for support files. Manually constructing and debugging formatting issues on these files can be a major time burden on the development team, but the automated process provided by MADM is nearly instantaneous and generates robustly formatted simulation-ready files.

3 Workflow

MADM provides three primary capabilities: browse and analysis of materials and their associated support files, import of new material data, and export of stored material data. Each of these primary capabilities contain a set of features and functionality that assist in workflow and data utility.

3.1 Browse, Search, and Analysis

The Material and individual file tabs on the top row in Figure 2-6 (*.ems emissivity files, *.fit files for parametric BRDF models, SQT files for spherical quad-tree BRDFs, etc.) have features to enable convenient browse, search, and assessment actions.

3.1.1 Browse

The table at bottom of Figure 2-6 presents a list of all available database entries for the specified data type such as Material, EMS File, etc. The table columns contain key attributes to aide in browsing. The user can scroll through the table and select materials that have specific support collections, such as thermal solver properties or a DIRSIG Classic Emissivity-based Surface Description. Double clicking on an entry loads that material's details into the interface entries to better assess the material for a user's intended use. A scene designer may wish to browse DIRSIG "thumbnails" for a visual response resembling features and level of detail needed for a specific surface. A scientist may wish to browse for materials that utilize measurement-based BRDFs instead of parametric models. Both the thumbnail and the model are pieces of information readily accessible in the material UI.

Additionally, the material details include fields for any files referenced by the data sub-collections, such as an EMS file for a DIRSIG Classic Emissivity surface. Any referenced file will have an Open button next to it, that will both switch the UI to that file's particular interface and load the contents of the referenced file. The UI for files provides both general file information as well as key summary information about the contents of the file such as quantity or range of spectral samples. In addition, some files provide visualization tools for their contents, detailed in Section 3.1.3.

The tables in the data sub-collection's UIs can also be used to browse through the stored files. Double clicking on a file entry will load that files details into the UI fields. If after reviewing a files details, the user is interested in materials that utilize this particular file, click on the "Search for All Materials Using this File". This will both switch to the Material UI and list a subset of materials in the table at bottom. This subset will contain only files that reference the support file of interest and can be browsed as usual.

3.1.2 Search

In addition to browsing, MADM also provides a robust search function. Searchable fields can be found in almost every UI frame, and they can be identified by the check button next to the field name. Once the Search feature is activated, simple mouse clicks perform a database query that looks for all entries containing the specified value. The results from the query appear as a subset of materials listed in the table at bottom. To view information on a material returned in a search, the user need only double-click on the entry to display the information in the UI fields.

3.1.3 Analysis

Material analysis assesses the particulars associated with selected materials, e.g., necessary DIRSIG radiometry solvers, details for attribution of properties with object surfaces, or plots of spectral responses. MADM's UI is setup to quickly provide visible access to the technical details of each material in order to identify properties of interest.

Fields for almost every data element are available in the UI, giving a user access to not only the collection itself, but the technical details for each entry. After identifying a material, the user can review the fields for, e.g., appropriate solvers and available surface property data. If a surface property includes a file, the user can easily access the file by clicking the "Open" button. This will open the specific support file tab and load the file of interest into the UI. The summary fields can be reviewed to assess if the file covers the desired spectral range or if suitable sampling exists to satisfy the user's needs.

For support files that have large amounts of data, such as an emissivity file, the user can plot the data. The plot can be interacted with, allowing a user to zoom and pan around the figure to look for the presence of specific features that may be responsible for an artifact, or to ensure the data was acquired with adequate spectral or spatial sampling. Some support files, such as those describing BRDFs can produce 3-D plots that can be manipulated for rotation as well.

3.2 Import

The import functionality for MADM is designed to be extensible to allow for the incorporation of growing number of formats and sources. MADM's initial purpose was to manage DIRSIG material and related files, so DIRSIG *.mat files are the only current file format that is supported, and the following discussion will focus on it.

The DIRSIG MAT FILE import tab is shown in Figure 2-5. This tab provides the interface for loading, reviewing, and controlling material entry imports from DIRSIG *.mat files. The user can select a file for import by typing the filename in or utilizing the file browser. Once the filename is identified and loaded, the status appears in a log window. Upon successful file load, two additional events will happen. First, the table at bottom will list all material entries contained within the .mat file. The second event that occurs upon successful load is the population of default support file paths. These defaults are based on a combination of the source *.mat file's path, the common materials directory structures found in DIRSIG simulation demonstrations, and locally developed simulation structures. The defaults serve as convenient starting points for all directories, but they can be modified to account for any support file locations.

After reviewing the material entry contents and updating any support file paths the material can be imported by selecting the Import Entry button. The import processing functions are run on selected data, and the status is again display in the IMPORT LOG. The log will indicate if support files associated with the import already exist, so if the files have already been captured in the database, the new entry will reference the existing entries instead of adding additional copies of otherwise redundant information. This promotes efficient storage.

Additionally, MADM provides an "Import All" button that allows all entries from a single DIRSIG *.mat file to be imported. In addition to status for each material entry, the IMPORT LOG will provide a summary of the import, listing the number of both successful and failed imports. If a failed import is found, the user can review the IMPORT LOG, identify the responsible material entry, review its contents in ENTRY DATA, and assess the root cause of the error.

Upon successfully completing an import, the material entry can be found in the material tab table as part of the browsing process and clicking on the entry will display its contents for assessment.

Currently, the DIRSIG *.mat file import process is standardized and executed in its entirety when the "Import Entry" or "Import All" buttons are selected. Additional and optional processing elements in the import chain are planned, and they will be accessible under an options frame.

3.3 Export

The export functionality for MADM is designed to be extensible to allow for the incorporation of growing number of formats and pre-export processing options. Currently, DIRSIG *.mat files are the only file format that is supported, and the following discussion will focus on it.

The export tab is shown in Figure 2-6. This tab provides the interface for exporting MADM contents from the database to a file system.

The user can select files for export by either browsing the material tab and using the "Add Export" button or by typing file names into the Export list. The output path can be specified by browsing or typing the path in manually. This output path is where MADM will create and populate a directory structure containing the material entries and support files in the format specified. The directory structure itself can be affected with the options check buttons, and the format is selected by pressing the button that corresponds to the end use. Currently only DIRSIG mat files are supported, and they can be generated by pressing the "Export for DIRSIG" button. Once complete, the requested directory structure and file elements can be found in the specified export path.

Additional options and output formats are under development to support a wider variety of material data stored for each entry.

4 Industry Impact

Originally intended as a storage and organization tool to aide development of scenes for DIRSIG, MADM's current and evolving features will provide a robust environment to manage material properties data for variety of purposes.

MADM's flexible import, management, and export functions allow "one-stop shop" aggregation of data from such diverse sources such as the Non-conventional Exploitation Factors (NEF), NASA MODIS-ASTER, and AFRL Satellite Assessment Center databases, as well as data from laboratories and universities. Further, files can be easily exported in formats used by additional software tools, such SVST, COAST/FIST, or COTS software like Maya or Arnold.

MADM provides a mechanism to record the pedigree of any material used in a radiometric simulation. Having a record of how particular MADM material entries were processed on both import into the database and export as simulation inputs enables a comprehensive view of how the exported properties were established. This feature can be highly beneficial to phenomenologists and scientists who want to use the radiometry simulations to understand the physics and phenomena of underlying signatures.

Providing a variety of input and output formats with MADM will provide access to a wide variety of data sources and enable consistency in simulation development, analysis, and production across users and applications. Additionally, MADM can promote the development of advanced radiometric image rendering techniques: A graphics artist can use COTS 3-D tools to build synthetic structures and use MADM to export material properties in shader format for use in COTS rendering engines. COTS rendering engines, while less robust, are built for speed; a DIRSIG scientist can take the same 3-D structure, export a version of the materials that support a slower radiometric engine like DIRSIG and examine the differences between the two to guide continued development of DIRSIG or complementary / successor tools.

Finally, by providing access to data sources, measurement methods, and processing steps, MADM can enable comparison studies between lab and field measurements to assess real-word effects like material aging. If an analyst or scientist can identify spectral features in a lab or field measurement, they can use MADM's tool set to look for materials with measurements that also contain those features. Or conversely, if a mission planner is trying to develop a mission to capture targets of known materials, MADM can provide access to the measurements for those materials that can aide in the optimization of a capture system that can collect the key features for a given material.

5 Conclusion

MADM is a powerful storage and management tool for material properties. It provides flexible, robust capabilities to support radiometric simulations as well as signature studies that rely on accurate material definitions and measurements. These capabilities are wrapped in a Graphical User Interface that can be leveraged by diverse users spanning a range of technical backgrounds. The ability to consolidate material measurements from a variety of sources, represent them in a range of formats and models, along with the tools to interact with this information means MADM will reduce development times, increase data utility for a wide range of tasks, and increase confidence in radiometric simulation results.

MADM's development scope was initially much smaller, focused on providing access to a centralized set of materials for use in DIRSIG. However, it was recognized that MADM provided an opportunity to address a much wider scope with little additional effort. As a result, MADM is undergoing spiral development to provide additional storage and tools for source data, alternative import and export formats, and more exporting options. Two near-term developments include incorporating material measurement data taken with at AFRL SNOBAL optical properties laboratory and tools to process material data into 3-D graphics shaders formats.

[1] C.D. Demars, D.W. Tyler, D. Allen, J.A. Dank, and M.C. Roggemann, "Multi-spectral shift-estimation error calculations using simulated phenomenology," Appl. Opt. **57**, 30, pp. 8989-9004 (2018).

[2] D.W. Tyler and J.A. Dank, "Cramer-Rao Lower Bound calculations for image registration using simulated phenomenology," J. Opt. Soc. Am. A **32**, 8, pp. 1425-1436 (2015).