Computer Integrated Surgery II
Michael Mudgett
Group 8

Critical Review: "Spektr: A computational tool for x-ray spectral analysis and imaging system optimization"

Siewerdsen, J. H., et al. "Spektr: A computational tool for x-ray spectral analysis and imaging system optimization." *Medical physics* 31.11 (2004): 3057-3067.

I chose to review this paper for my background presentation because it proved to be extremely helpful for my project. I needed an effective method of generating x-ray spectra for a variety of x-ray configurations and the model established in the paper is what I decided to go with. Even though I will be using the newest version of Spektr (Spektr 3.0), I chose to review the 2004 paper, which details the original Spektr release. I did this because it has a deeper explanation of the fundamental methods underlying the model, there is a stronger effort to validate the model, and the discussion takes an in-depth look at its advantages and shortcomings.

The paper starts by introducing the model that the author is putting forward. It explains that the program is written in MATLAB, has a GUI, and is available as a free download. Furthermore, it touches on the capabilities, specifically the flexibility with parameters such as kVP and added filtration. Next, it touches on the methods used to build the model. There are two primary components of the tool, the "spectrum()" function and the "beers()" function. The former is used to develop the rough shape of the x-ray spectrum based on the TASMIP algorithm. Not much detail is provided on this algorithm and further investigation is left up to the reader. This is a very large part of the program since it gives the main structure of the spectrum curve, by fitting a polynomial to measured data at specific kVp values. I would note here that the main difference made in Spektr 3.0 is that TASMICS is applied, where the curve is generated by cubic splines in favor of polynomials. The latter function is used to filter the spectrum based on the filters applied by the user. The author states that this part is calculated by Beer's law of exponential attenuation, which is once again left to the reader to investigate.

Overall, I was expecting more detail from the methods section but upon learning that the two main components have been established, it makes sense to leave out the fine details. Furthermore, the author states that those are the two main functions but does not explain the other functions provided in Table 1. While some of them are trivial, I think that providing more detail on more of the functions could have been valuable. However, the code is provided for free, so they aren't hiding any information.

After discussing the methods, the authors move on to describe the validation work that was done on the model. There were three main experiments done, shown in Figure 1. The first was a comparison between TASMIP and Spektr curves at three different kVp values. The curves are very similar which was expected since Spektr implements TASMIP. The small differences between the models are attributed to slight differences in interpolation. The other two experiments compare the model to physical data. Experiment 2 compared the tube output (mR/mAs) to the Aluminum thickness in the tube and kVp. The graph shows that the calibrated prediction does a very good job of fitting the measured data. Finally, the third experiment explains the motivation behind the calibration process, since the difference between the predicted and measured tube output varies as a function of Tungsten thickness in the tube.

I felt that this section of the paper was particularly lacking. I was looking forward to reading a thorough validation procedure with experimental data compared to model data in many different contexts. Nonetheless, the author states in the introduction that the goal of the paper is to introduce the computational toolset and extensibility model they have developed. The author does not explain why they did not do much validation (e.g. lack of experimental data points) but I personally think that more could have been done to convince the reader of the validity of the model, especially under different filtering scenarios.

The next section of the paper concerns the graphical user interface of the program. The author explains the different inputs and outputs of the display and the different parameters users can tweak. The fact that the author took the trouble to incorporate the model into a convenient and straightforward GUI is very impressive. I have seen many programs which are released only as code, leaving the user to adjust parameters and arguments in the code files. The authors wanted to make this model accessible to a large audience and have succeeded in doing so.

After this section, the author switches to "Part B" of the paper, which explores the "Application to Imaging System Optimization." This part of the paper is almost completely irrelevant to me because I only want to use Spektr to generate spectrum files that I can feed into MC-GPU and generate x-ray images. However, the authors wrote the program to be versatile, and chose to expand on an application they found exciting. To explore Spektr's ability to optimize a proposed imaging system, the paper selects a group of systems and goes about quantifying their performance and searching for ideal parameters. They start by taking four different detector types, some corresponding to commercial models and some representing detectors that are theoretical/under development (as of 2004). Next, they give an in-depth look at the different metrics used to evaluate an x-ray setup. To do this, the author employs "Cascaded Systems Analysis," which estimates detector performance based on a set of parameters. The author indicates that the paper provides a very high-level view of the process, aiming to provide a "proof-of-concept" rather than an exhaustive analysis. After this, equations are provided for the fluence per unit exposure, detector sensitivity, detective quantum efficiency (DQE), and some of the cascade parameters. Not much information is given on how these come together to evaluate detector performance, and of the terms go over my head. I believe that this section is valuable for explaining the methods used to quantify a specific imaging system, but I am unsure if it needed to be explained as much as it was if cascaded system analysis is an established procedure.

Furthermore, the fact that this section is longer and contains more equations than the “Methods” section used to build their model is unexpected.

The paper then describes the results of adjusting filter materials and thickness in the four systems. Many different graphs are included which show how fluence per unit exposure, QDE, and detector sensitivity change as a function of filter thickness and material type. Note that material type is quantified by Z, the attenuation constant. The figures make it clear that the relationship is “not trivial” and that the parameters are subject to a complex relationship. Furthermore, they illuminate the fact that small changes in the physical elements of the system can have large effects on the detector performance.

After exploring the changes caused by differences in filter parameters, the paper investigates the effect of kVp and beam filtration. The author takes the optimal filter material and then varies kVp and filter thickness, calculating the same performance metrics as in the last section. Once again, the process reveals a complex relationship between the two parameters.

Finally, the author moves on to formulate a discussion and draw conclusions. The author first states the general accomplishments that the paper discussed, including a model which can generate x-ray spectra and can calculate spectral characteristics. He then discusses the results of the experiments performed on the four imaging systems. It is clear from the wealth of data generated that using the model is much faster and easier than collecting the data experimentally. Furthermore, the plots provide clear locations that maximize certain parameters, allowing a designer to select specific system parameters (kVp, filter thickness, filter material) and achieve their desired performance. This part describes how this one experiment was just a small, exploratory effort to shed light on the wide range of possibilities that Spektr can be used for.

The next part of the discussion focuses on critiquing the model. The paper states that there are many aspects of x-ray systems that Spektr does not address, specifically depth-dependent absorption, polyenergetic input spectrum, K-fluorescence, and the effects of subject contrast on filtration. In addition, the model is limited in that it does not allow for dynamic selection of beam kVp and filter properties, and it also assumes that the x-ray tube can tolerate any heat load burden, which is not realistic. Other shortcomings of the model are mentioned as well.

I think that the paper does a good job of analyzing the flaws in Spektr, which is necessary for improving any model. At some points, I feel as if the author is too hard on the program, since there are certain aspects one cannot account for (subject contrast) and some points are too difficult, computationally challenging, or ineffective to worry about. Models can never perfectly describe nature, but they can still be very useful. Nevertheless, the author notes the value of Spektr, and we know that Spektr has improved since its initial release.

In summary, I think that the paper presents a very useful and interesting model for describing x-ray spectra. It will play a very important role in my project and I appreciate the fact that the author made the program easy to use. Because I am simply using Spektr for spectra generation, I wanted to learn more about the methods and validation and didn't care about the potential value in optimizing physical imaging systems. However, I see the value in this and I am sure that many readers identified a lot of opportunities in that section. The paper explains the program well, identifies the issues with it, and creates a plan for moving forward. Overall, I think the information is well-presented and accessible for someone like myself, who knows little about x-ray imaging.