# Cdmam_Fit_3: A Graphical User Interface for Mammographic Contrast-Detail Analysis

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## Abstract

According to the European Guidelines for quality control in digital mammography, mammographic image quality is expressed in terms of threshold contrast visibility using clinical exposure settings. The threshold contrast is defined as the lowest contrast value for which the objects are visible. The Contrast-Detail MAMmography (CDMAM) phantom is commonly used for the contrast-detail analysis, i.e. the detection of small thickness and low contrast objects. An automated scoring software tool (called CDCOM) was recently developed to evaluate the CDMAM radiographs. However, the CDCOM program does not determine the threshold contrast and further analysis is required by the user. This work presents a MATLAB-based graphical user interface (GUI), called CDMAM_fit_3, that a) reads and converts the original CDCOM data to a probability matrix, b) applies a psychometric curve fit to the data, c) predicts the human readout, d) compares the predicted results with the acceptable and achievable limits (provided by the European Guidelines) and e) saves the output data in various formats (i.e. txt, csv, xls, xlsx and xlsm). An executable version of the CDMAM_fit_3 can be used by the user without any programming and data processing knowledge.

**Key words:** MATLAB-based Graphical User Interface, Contrast-Detail Analysis, Mammography, CDMAM Phantom

## Introduction

According to the European Guidelines for quality control in Full-Field Digital Mammography (FFDM), threshold contrast (i.e. the lowest contrast value for which the objects are visible) visibility is used to express the image quality under clinical conditions[1,2]. The Artinis Contrast-Detail MAMmography (CDMAM) 3.4 test tool[3] is commonly used for the contrast-detail analysis, i.e. to find the detection limits of low contrast and small details objects. The CDMAM phantom consists of a 16 cm x 24 cm x 0.3 mm Aluminum (Al) plate with 205 square cells (arranged in 16 rows x 16 columns). Each cell contains two identical gold discs (one at the center and one in a randomly chosen corner, i.e. eccentric disc) of given thickness and diameter that decrease logarithmically to cover a range of object diameters from 2.00 to 0.06 mm in each column and thicknesses between 2.00 and 0.03 mm in each row. Both ranges are selected to simulate the respective size and contrast ranges for microcalcifications. The CDMAM phantom is used to determine the contrast limit (threshold contrast) or threshold gold thickness for a given disc diameter that corresponds to successful observation of the eccentric disc location. The Al base is attached to a 5 mm thick polymethyl methacralate (PMMA or plexiglas) cover and the CDMAM phantom is usually inserted between two PMMA plates of 20 mm thickness each[1,4]. This combination under a 28 kV Mo/Mo radiation beam corresponds to a total attenuation approximately equal to 50 mm PMMA, which has been shown to be

equivalent to breasts of typical composition with a compressed thickness of 6 cm[5].

The evaluation of the CDMAM test object is usually based on reading of CDMAM radiographs by human observers. To implement this, contrast-detail measurements rely on a large number of observer readings. However, this procedure suffers from three main drawbacks: a) the presence of significant inter-observer error decreases the reliability and confidence in the measurements, b) the evaluation may be biased from memory effects in the human observer because it is practically focused to a specific number of cells and c) it is time consuming[1]. Automatic scoring softwares for the evaluation of the CDMAM phantom were developed by Karssemeijer and Thijssen[6], Yip et al.[7] and Prieto et al.[8] to provide a reliable and less time consuming alternative to human readout. The first software was further developed by Veldkamp et al.[9] and Visser and Karssemeijer[10] to create the CDCOM software tool, which is widely accepted by researchers and the scientific community, and is supported by the European Reference Organisation for Quality Assured Breast Screening and Diagnostic Services (EUREF).

According to Visser and Karssemeijer[10] at least eight CDMAM radiographic images need to be captured in order to extract the contrast-detail curves. However, the CDCOM software does not combine the data from more than one image or determine the threshold contrast. Instead, it provides two output files, one with eccentric disc results and the other with centre disc results. The data is in a form of a 16 x 16 matrix, where 1 is a correctly located disc, 2 is an incorrectly located disc and -1 is a cell that is not in the phantom. Further analysis is required from the user. This study suggests a new MATLAB-based Graphical User Interface (GUI), called CDMAM_Fit_3, that reads the CDCOM output data and converts them to a probability (i.e. from 0.25 to 1) matrix, applies edge padding and smoothes the probability data (via convolution) using a Gaussian (3 x 3 mask with $\sigma$=1) filter[11]. Next, it applies psychometric curve fit and predicts the human readout threshold thickness using a power function[12]. The results are fitted (in semi-logarithmic scale) with a third order polynomial function to obtain the contrast-detail curve[4]. Finally, the software gives the option to save the predicted results in various formats (i.e. as txt, csv or in Excel).

## Materials and Methods

Figure 1 shows a photograph of the CDMAM 3.4 test tool[3] used for the Mammographic Contrast-Detail analysis. The phantom consists of an Al plate with 205 square cells (containing a central and an eccentric disc) that are arranged in 16 rows (thicknesses between 2.00 and 0.03 mm) and 16 columns (diameters from 2.00 to 0.06 mm).
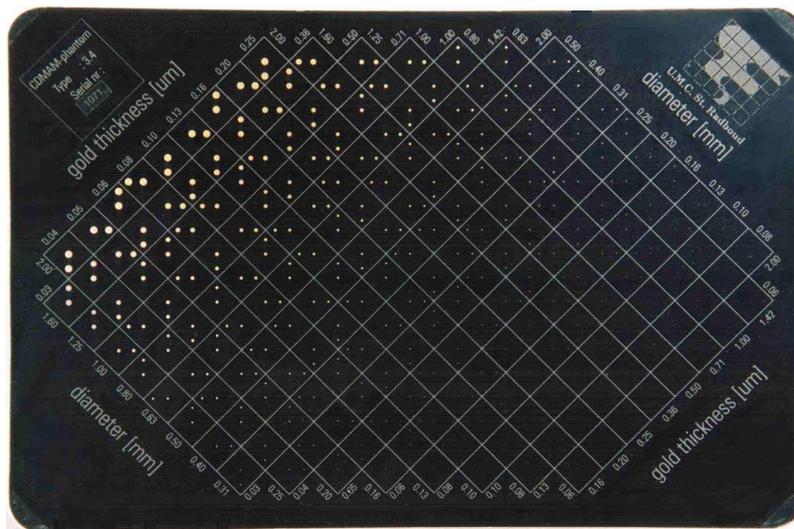
**Figure 1.** Photograph of the CDMAM 3.4 phantom from Artinis Medical Systems[3]

The detection probability is in the range between 0.25 (i.e. random guess of the eccentric disc corner) and 1 (i.e. perfect detection). Hence, the detection rate of p(t)=0.625 represents the mid-point between these two extremes and defines the threshold between correct and wrong indications. The psychometric curve fit can be applied using the following formula[11]:

$$p(t) = \frac{0.75}{1 + e^{-f(\frac{t}{t_T})}} + 0.25 \tag{1}$$

where $p(t)$ is the probability to detect a disc, $t$ is the disc thickness (in μm), $tT$ is the threshold thickness (i.e. the thickness that corresponds to p(t)=0.625) and $f$ is a free parameter to be fitted. As an example, Figure 2 shows a psychometric curve fit used to define the threshold thickness.
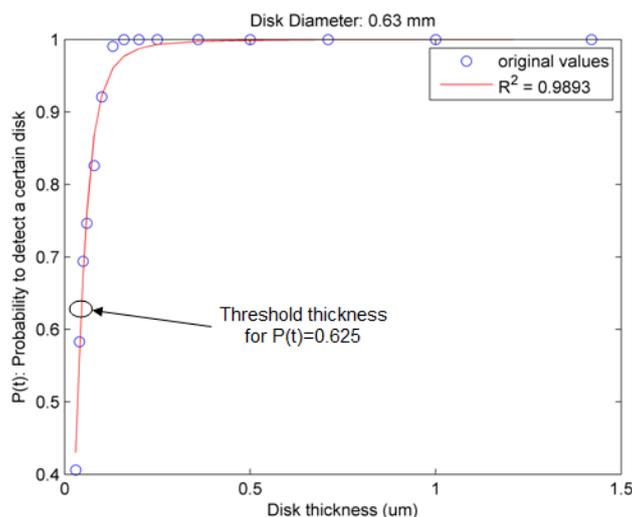


**Figure 2.** Psychometric curve fit used to define the threshold thickness

It was found that the results of the CDCOM software are different compared to those from human observers and the relationship between human and computer readouts follows a power function[10]:

$$TC_{human} = a\left(TC_{CDCOM}\right)^{n} \tag{2}$$

where *a* and *n* are coefficients to be fitted using the least squares approximation. It was found that both *a* and *n* parameters vary slightly for different diagnostic centres and Van Engen *et al.*[4] combined the data from three diagnostic centres to provide average factors equal to a=1.17 and n=0.888.

Finally, the resultant predicted human readout threshold thicknesses are fitted (in semi-logarithmic scale using the natural logarithm of the predicted threshold thicknesses) with a third order polynomial function to obtain the contrast-detail curve[4]:

$$\log(t_T) = ax^{-3} + bx^{-2} + cx^{-1} + d \tag{3}$$

where *x* is the detail diameter (in mm), and *a*, *b*, *c* and *d* are coefficients adjusted to achieve the least squares fit (including 95 % confidence interval). The final results (i.e. human predicted *tT*) can be compared with the acceptable and achievable limits, provided by the European Guidelines for quality assurance in breast cancer screening and diagnosis[2].

## Results and Discussion

Figure 3 shows the first tab (**Insert data**), used to insert and pre-process the CDCOM output data. The software gives the option to insert the data in various formats: txt, csv, Excel (xls, xlsx or xlsm) or read from the clipboard (Figure 3). The original results are shown in the table of Figure 3. Next, by pressing the **Probability & Gaussian** button, the software converts the original CDCOM data to a probability matrix (i.e. between 0.25 and 1), applies edge padding (to deal with boundary conditions in data processing) and smoothes the data (via convolution) using a Gaussian filter (3 x 3 mask with σ=1). Further details about this process are given in Verbrugge thesis[11]. The probability and Gaussian smoothing results are shown in the same table (Figure 4).
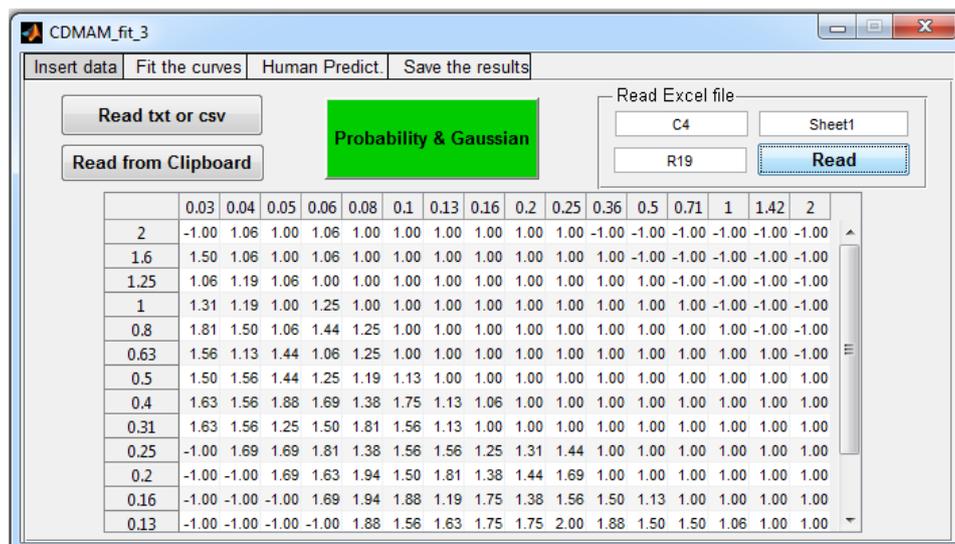


**Figure 3.** *Insert data* tab: Several was to insert CDCOM results to CDMAM_Fit_3
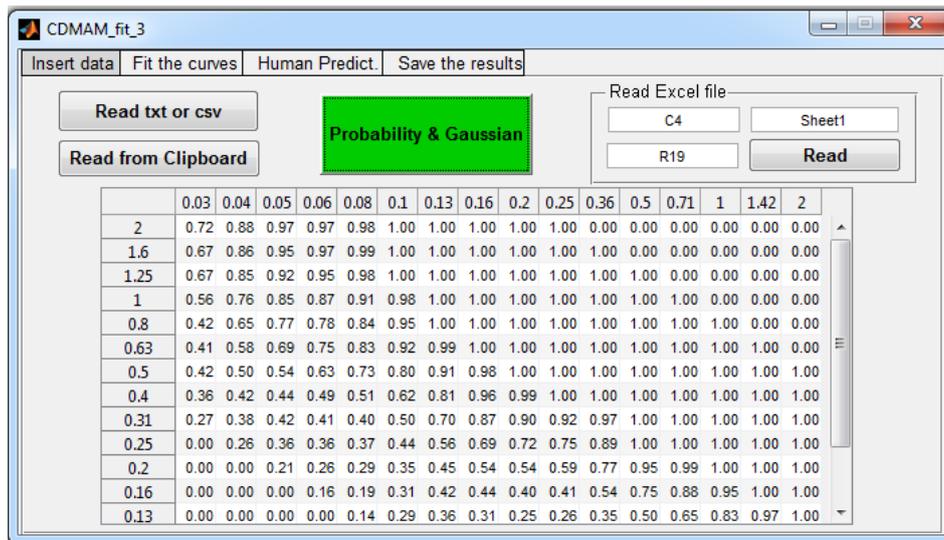
**Figure 4.** *Insert data* tab: Calculate the probability matrix, apply edge padding and Gaussian smoothing

Figure 5 shows the second tab (**Fit the curves**) of the CDMAM_Fit_3 software, where psychometric curve fit (based on Equation 1) is applied to the data. The fitting works well in the disc diameter range of 0.1-1 mm, but not very well for extremely small (0.06 and 0.08 mm) and large (1.25, 1.6 and 2 mm) disc diameters. This happens because the p(t) is usually less than 0.25 and more than 0.75, respectively. In order to have consistent fitting results compared to the "normal" disc diameter range (i.e. 0.1-1 mm), extrapolation can be applied using f(0.1 mm) (i.e. the f value that corresponds to t=0.1 mm) for very small disc diameters and f(1 mm) for very large disc diameters. It was found out that the first extrapolation is inevitable because the p(t) values are usually very small (e.g. for t=0.06 mm they are in the range 0.3-0.4). Therefore, the software applies this extrapolation by default. On the other hand, the latter case can be avoided (i.e. for large disc diameters) because sometimes the R2 (coefficient of determination) of the original fitting can be higher than the extrapolated one. The comparison (both visually and using R2) between the psychometric curve fit results and the extrapolated ones (for large discs) is also shown in the second tab (Figure 5). Hence the user has the option to select between the two sets of results.
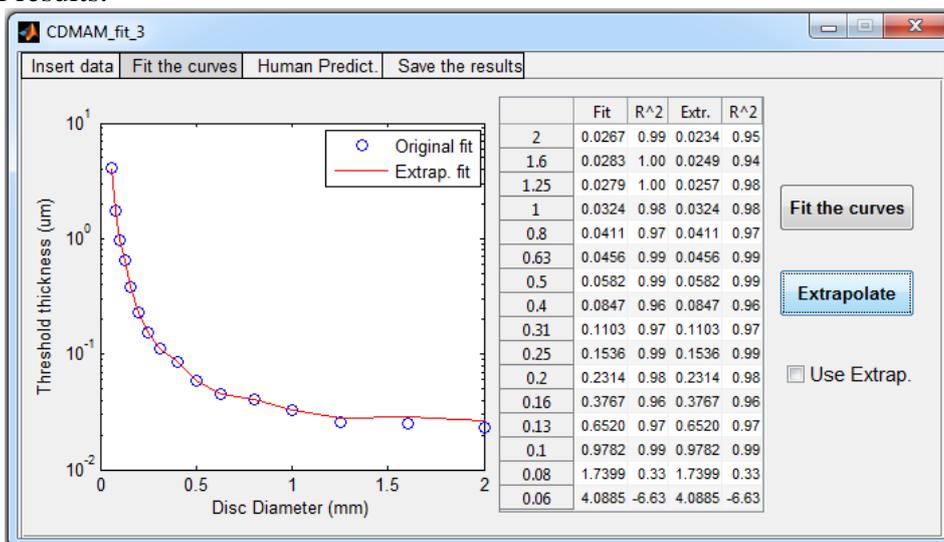


**Figure 5.** *Fit the curves* tab: Apply the psychometric curve fit and extrapolate for large discs (1.25-2

mm)

Figure 6 shows the third tab (**Human Predict.**) of the software where the human predicted readout results are calculated (using Equations 2 and 3) over a range of disc diameters. The software presents the final results (with the 95 % confidence intervals) and compares them to the acceptable and achievable limits provided by the European Guidelines[2].
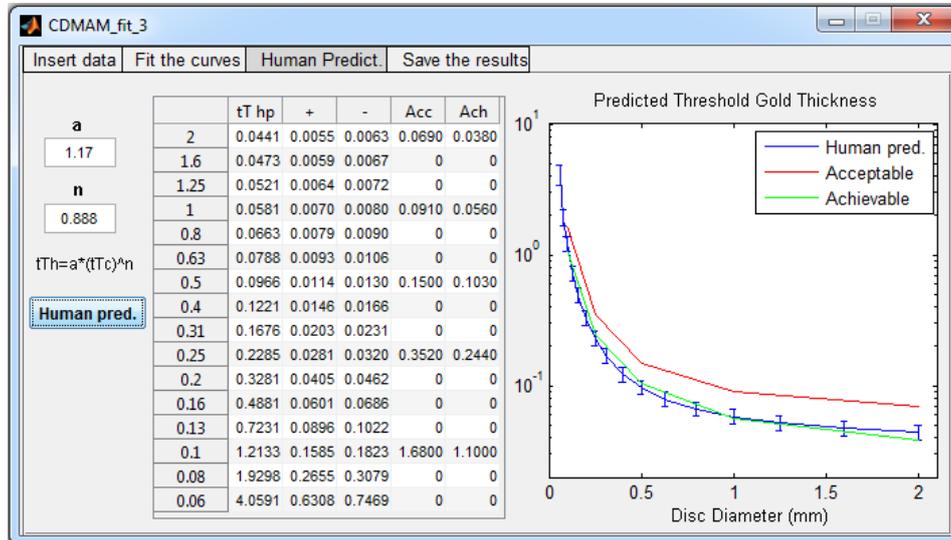


**Figure 6.** *Human Predict*. tab: Calculate the predicted threshold gold thickness and compare the results to the acceptable and achievable limits

The software also compares in separate figure the results with the limits (Figure 7). When the predicted threshold thickness value is within the limits the background colour of the specific thickness (i.e. same row) is orange. Otherwise, it is either red (when it is above the acceptable limit) or green (when it is below the achievable limit). It should be noted that small threshold contrast corresponds to high performance because less contrast is required to detect a disc of specific diameter.
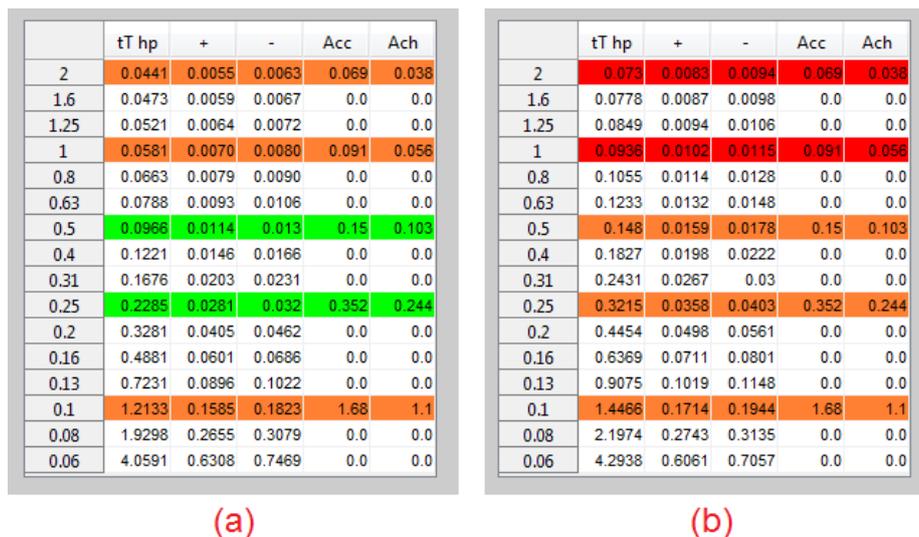


**Figure 7.** Comparison between the predicted threshold thickness and the acceptable / achievable limits

Finally, the fourth tab (**Save the results** - see Figure 8) can be used to save the results (i.e. the predicted threshold thickness, 95 % confidence interval, and acceptable / achievable limits over a range of disc diameters) as txt, csv or in Excel
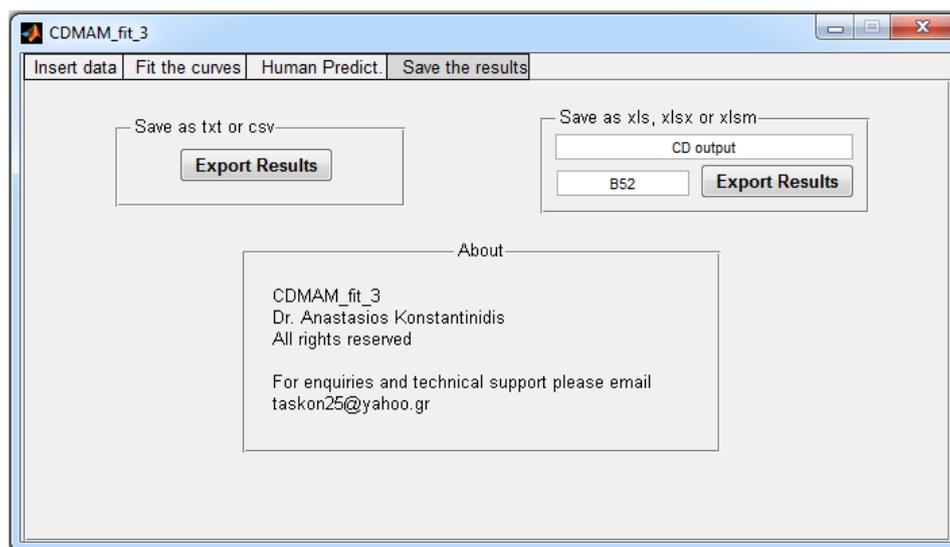
(as xls, xlsx or xlsm).



**Figure 8.** *Save the results* tab: Save the results as txt, csv or Excel file (xls, xlsx or xlsm)

The CDMAM_Fit_3 threshold thickness results were compared to the respective of a well established software product (called CDMAM_Analysis_V1_5_5[13]). The CDMAM_Analysis_V1_5_5 software is also a MATLAB-based GUI that process directly the CDMAM images (using CDCOM) and offers several input and output options. Figure 9 shows the comparison between the two softwares (from 0.1 to 1 mm disc diameter).
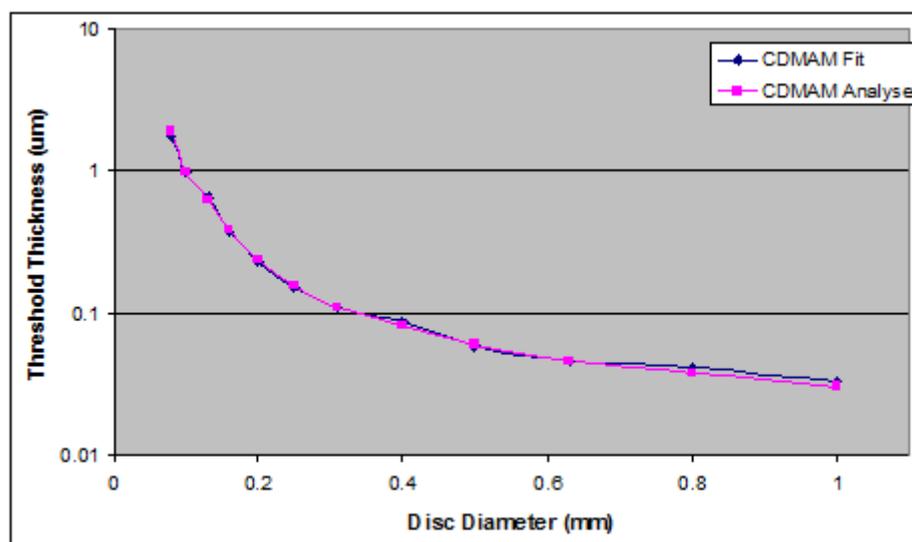


**Figure 9.** CDMAM_Fit_3 versus CDMAM_Analysis_V1_5_5 (in terms of threshold thickness)

The comparison was further quantified using the relative difference (%). It can be observed in Figure 10 that the results are in agreement (less than 9 % difference over the whole frequency range).
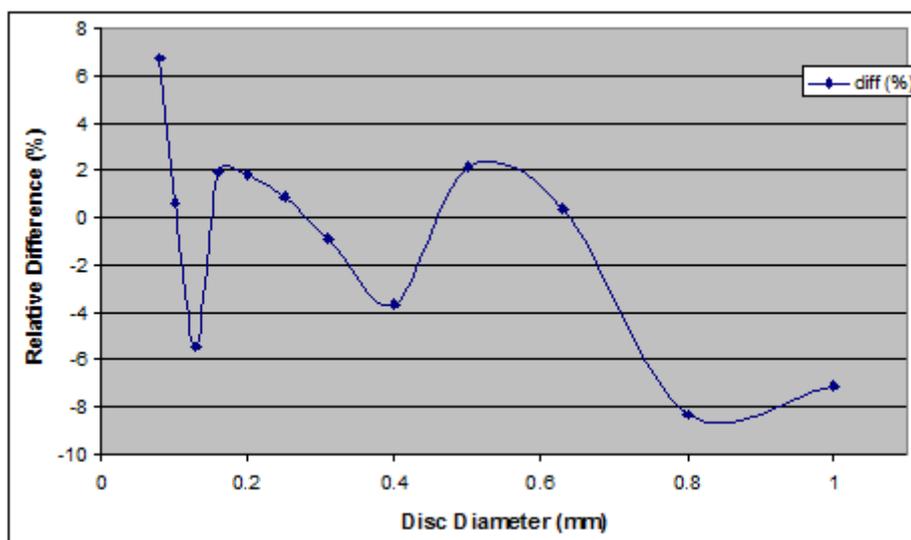
**Figure 10.** Relative difference (%) between the two software products

## Conclusion

This study suggests a new MATLAB-based GUI (named CDMAM_Fit_3) to apply psychometric curve fit on raw CDCOM results. In particular, CDMAM_Fit_3 a) reads and converts the original CDCOM data to a probability matrix, b) applies a psychometric curve fit to the data, c) predicts the human readout, d) compares the predicted results to the acceptable and achievable limits (provided by the European Guidelines) and e) saves the output data in various formats (txt, csv or Excel). The software can be further developed to offer more options (in terms of input, output, fitting, etc).

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