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**Zagazig University  
Faculty of Science  
Department of Mathematics**



**جامعة الزقازيق  
كلية العلوم  
قسم الرياضيات**

# **COMPUTER SCIENCE APPLICATIONS IN RENEWABLE ENERGY**

**BY**

***MOHAMMED ABDELFATTAH ALI AHMED***

**(B. Sc. in Computer Science 2008)**

**A Thesis Submitted in Partial Fulfillment**

**of**

**The requirements for the Degree of**

**Master**

**in**

**Computer Science**

**Department of Mathematics**

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**Zagazig University**

**2016**



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*Computer Science Applications  
in Renewable Energy*

By

*Mohamed Abd El-Fattah Ali Ahmed*

*A Thesis Submitted in Partial Fulfillment of the*



*Requirements for the Degree of Master*

*in Mathematics (Computer Science)*

To

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## ACKNOWLEDGEMENT

First, I would like to thank **ALLAH**, the most merciful for guiding me to do this work. I hope he with his majesty accepts it and makes it a reason to enter paradise.

I would like to express my appreciation to **Prof. Dr. Mohamed El-Sayed Aly Youssef** and **Dr. Gasser El-Hussein Gad El-Rab Hassan**, for their continuing guidance, help, advice and support throughout the progress of this work, and for their keeping patient on me during this work.

I wish to express my thanks for **Prof. Dr. Walaa Seha**, **Prof. Dr. Fawzan Ismail Sidky** and **Dr. Zahraa El Slayed Mohammed**, for their supportive help, and guidance.

I would like to express my deep gratitude and great thanks from my heart and mind for **MY PARENTS** and **MY WIFE**, for their encouraging me not only in this work, but in all my life with their endless support and kindly help.

I would like to thank my brother, my sisters and all my relatives for their kindness and supportive help during this work.

I would like to thank my friends at City for Scientific Research and Technology for helping and supporting me, with special appreciate to **Prof. Dr. Bayumi** and **Eng. Alaa Hassan Hassan**.

Thanks to all who helped me in achieving this work.

To **MY WIFE** and **MY** children **ROAA** and **AHMED**

***Mohammed AbdelFattah Ali Ahmed***

## **ABSTRACT**

Nowadays, computer science plays an important role in all fields of knowledge. Many problems in different areas can be solved effectively using computer science. Computer science has the ability to model and analyze problems as well as design solutions and verify that they are correct, also comparing different techniques until identify the best one.

In this regard, this work employed the computer science to solve one of the important issues in energy field; in solar systems, accurate knowledge of solar radiation data is considered the first step in resources assessment in a certain location. The unavailability of the solar radiation measurements for different locations around the world leads to developing various models to estimate the solar radiation.

The Artificial Neural Network (ANN) models have been employed in this study to estimate global solar radiation on a horizontal surface. Furthermore, the performances of ANN models are compared with the performances of different empirical models that have been used from literature or presented in this study.

Moreover, different software engineering activities (system specification, design, validation, and evolution) are utilized in this work to implement a new in-house software program for validating and verifying which model is suitable to evaluate global solar radiation over Egypt. In addition, this software program can be used to analyze weather data and to support essential information for designing energy systems. This software has been developed using C# programing language.

The performances of ANN models which have been designed in this study showed very good estimation for global solar radiation on a horizontal surface. In addition, the most accurate empirical models in estimating global solar radiation from models that used in this study are recognized.

As well, the performance of accepted models that derived from new presented empirical models in this study are more accurate than the selected models from the literature. Also, the local formula for the most accurate new model provides good estimation at different locations especially at coastal sites where inaccurate estimations are commonly predicted by different models. Also, the local and general formulas of the best model also perform better than the most accurate two sunshine-based models from the literature.

In addition, the performance of the best ANN model and best empirical model in this study are compared. The results illustrate that two models have a very good performance and their performances are very closer to each other and the best performance is donated by ANN model.

The presented results in this study are significant for quick and accurate estimation of global solar radiation. The models and the computer code which are developed in this work form the backbone of any computer-aided in design of different energy systems.

## LIST OF PUBLICATIONS

<b>Publisher</b>	<b>Journal</b>	<b>State</b>	<b>Paper</b>
Elsevier	Applied Energy	Published	New Temperature-based Models for Predicting Global Solar Radiation
AENSI	Advances in Natural and Applied Sciences	Published	Investigating the performance of different models in estimating global solar radiation
Elsevier	Journal of Atmospheric and Solar-Terrestrial Physics	Accepted with Revision	Performance Assessment of Different Day-of-the-Year-based Models for Estimating Global Solar Radiation - Case Study: Egypt
Taylor & Francis	International Journal of Green Energy	Under Review	Performance Assessment of Different Global Solar Radiation Models – Case Study: New Borg El- Arab city, Egypt



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## LIST OF NOMENCLATURE AND ACRONYMS

<i>ANN</i>	Artificial Neural Network
<i>AST</i>	Apparent Solar Time
<i>a</i>	Empirical coefficient
<i>b</i>	Empirical coefficients
<i>c</i>	Empirical coefficients
<i>C</i>	The monthly average daily total cloud cover during daytime observation (Octal)
<i>CS</i>	Computer Science
<i>CBSE</i>	Component-Based Software Engineering
<i>d</i>	Empirical coefficients
<i>e</i>	Empirical coefficients
<i>E</i>	Relative percentage error
<i>Ele</i>	The elevation above sea level (m)
<i>ET</i>	Equation of Time
<i>f</i>	Empirical coefficients
<i>g</i>	Empirical coefficients
<i>G</i>	the monthly average daily global solar radiation on a horizontal surface ( $\text{MJ}/\text{m}^2 \text{ d}^{-1}$ )
$G_{on}$	Extraterrestrial radiation on normal plane ( $\text{W}/\text{m}^2$ Watt per square meter)
$G_{sc}$	Solar Constant ( $\text{W}/\text{m}^2$ equal to $1367 \text{ W}/\text{m}^2$ )
$G_{oH}$	Extraterrestrial radiation on Horizontal plane on a given time of year ( $\text{W}/\text{m}^2$ )
$G_G$	Global solar radiation
$G_{dir}$	Direct solar radiation
$G_{dif}$	Diffuse solar radiation
$G_t$	Total solar radiation on tilted surface
$G_{Bt}$	Beam radiation on tilted surface
$G_{Dt}$	Diffuse solar radiation on tilted surface
$G_{Gt}$	Ground reflected solar radiation on tilted surface
$G_B$	Beam radiation on horizontal surface
$G_{Bn}$	Beam radiation from the sun
$G_0$	the monthly average daily extraterrestrial global solar radiation on a horizontal surface ( $\text{MJ}/\text{m}^2 \text{ d}^{-1}$ )
$G_{i,m}$	The values of $i^{\text{th}}$ measured global solar radiation
$G_{i,c}$	The values of $i^{\text{th}}$ calculated global solar radiation

$\overline{G_m}$	The average value of measured global solar radiation
$\overline{G_c}$	The average value of calculated global solar radiation
<i>GSR</i>	Global solar radiation
<i>GUI</i>	Graphical User Interface
<i>h</i>	Solar hour angle
$h_{sr}$	Hour angle at sunrise
$h_{ss}$	Hour angle at sunset
$H_o$	Total extraterrestrial radiation on Horizontal plane during a day (J/m <sup>2</sup> Joules per square meter)
$\bar{H}_o$	Monthly average daily total irradiation on an extraterrestrial horizontal surface (MJ/m <sup>2</sup> d <sup>-1</sup> )
$\bar{H}$	Monthly average daily total irradiation on a terrestrial horizontal surface (MJ/m <sup>2</sup> d <sup>-1</sup> )
$H_{sr}$	Sunrise time from local solar noon
$H_{ss}$	Sunset time from local solar noon
<i>IDE</i>	Integrated Development Environment
$I_o$	Extraterrestrial radiation on horizontal plane by an hour period (J/m <sup>2</sup> )
<i>k</i>	Empirical coefficients
$\bar{K}_T$	Monthly average clearness index
<i>L</i>	Latitude angle
<i>LM</i>	Levenberg–Marquardt (ANN training algorithm )
<i>LST</i>	Local Standard Time
<i>m</i>	Air mass definition
<i>MAPE</i>	Mean Absolute Percentage Error
<i>MABE</i>	Mean Absolute Bias Error
<i>MBE</i>	Mean Bias Error
<i>MLP</i>	Multi-layer perceptron
<i>MPE</i>	Mean Percentage Error
<i>p</i>	The number of observation that taken into account
<i>r</i>	Correlation coefficient
$R^2$	Coefficient of determination
$R_B$	Beam radiation tilted factor
<i>RH</i>	The monthly average daily relative humidity (%)
<i>RMSE</i>	Root Mean Square Error
<i>RP</i>	Resilient propagation
<i>s</i>	The monthly average daily bright sunshine hour (hour)
$s_0$	Day length (hour)

$S$	Relative sunshine, $S = \frac{s}{s_0}$
$SCG$	Scale conjugate gradient (ANN training algorithm)
$SDK$	Software Development Kit
$SDLC$	Software Development Life Cycle
$SRTA-city$	City for Scientific Research and Technology Applications
$t$	The t-Test statistic
$T$	The monthly average daily ambient air temperature ( $^{\circ}\text{C}$ )
$\Delta T$	The monthly average daily difference temperature $T_{Max} - T_{Min}$ ( $^{\circ}\text{C}$ )
$T_{Max}$	The monthly average maximum daily temperature ( $^{\circ}\text{C}$ )
$T_{Min}$	The monthly average minimum daily temperature ( $^{\circ}\text{C}$ )
$VS$	Microsoft Visual Studio
$x$	Empirical coefficients
$y$	Empirical coefficients
$z$	Empirical coefficients
$Z$	Solar azimuth angle
$Z_s$	Surface azimuth angle
$\alpha$	Solar altitude angle
$\beta$	Surface tilt angle from horizontal
$\delta$	Solar declination angle
$\emptyset$	Solar zenith angle
$\theta$	Solar incident angle

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# Chapter 1

## INTRODUCTION

# **CHAPTER 1**

## **INTRODUCTION**

### **1.1 Research Motivation**

Today, computer science (CS) plays an important role in all fields of knowledge. Also, computer science has strong association with different disciplines; many problems in science, engineering, energy, health care, business, and other areas can be solved effectively using computer science. Computer science has the ability to model and analyze problems as well as design solutions and verify that they are correct, also comparing different techniques to identify the best one.

In this work the computer science is used for solving one of the important issues in energy field. In solar systems, accurate knowledge of solar radiation is considered as the first step in solar energy availability assessment. Also it is the primary input for different solar energy applications [1–4]. Since the solar radiation measurement are not available due to the high cost as well as equipment's calibration and maintenance [5,6], different solar radiation models are developed to estimate solar radiation. These models are proposed to predict solar radiation using different techniques such as using meteorological data and geographical data, as well as geostationary satellite images, artificial neural network (ANN), time series methods and stochastic weather methods [7]. Therefore, the best solar radiation models should be recognized to know solar energy potential before setting up any solar energy system.

## 1.2 Research Importance to Egypt

Egypt considers one of countries that is located in the most favorable solar belt which enjoys with abundant solar radiation (between 3,500 and 4,500 hours of sunshine per year) and solar energy magnitude between 12 and 30 MJm<sup>-2</sup> day<sup>-1</sup> [8]. Consequently, knowing the solar energy potential at any Egypt's location is important before setting up any solar energy system which can be considered one of the available solutions for supplying Egypt's energy demand [9,10].

## 1.3 Objectives

This work studied the following:

- Utilize Artificial Neural Network (ANN) models for estimating global solar radiation on a horizontal surface.
- Compare the performances of ANN models with the performances of different empirical models in predicting global solar radiation on a horizontal surface.
- Investigate the performances of different empirical models in estimating global solar radiation on a horizontal surface:
  - Evaluation the performances of the existing Egypt's models and recognizing the best model.
  - Assessment the performances of new international solar models over Egypt and identifying on the best models.
  - Introducing a new simple solar models for computing global solar radiation over Egypt with a higher accuracy.
- Moreover, employ different software engineering activities to implement a new in-house software to estimate global solar radiation over the whole Egypt and supporting essential information to design energy systems.

## 1.4 Thesis outlines

The rest of the thesis is organized as the following:-

- Chapter 2 contains an introduction about various software engineering activates, system models and system testing. As well, it discuss different artificial neural network (ANN) models. Furthermore, a literature survey of related studies which are carried out for estimating solar radiation using ANN models and empirical models.
- In Chapter 3 we describe and explain the data and methodology that used to model solar radiation. Besides, it shows the mathematical formulas of different models which used in this study. Also, it explores the design for our ANN models and discusses how the performances of the models is evaluated.
- In Chapter 4 we focuse on establishing and validating the performances of the used models in this study (Empirical models and ANN models). As well, it shows the results of comparison between the performance of the ANN models and empirical models. Also, it explores the calculated values of different statistical errors which have used for testing the applicability of models in estimating global solar radiation.
- In Chapter 5 we present the implementation of our software application and its features. As well as showing the programing code for some implemented classes and functions.
- In Chapter 6 we conclude the thesis work and suggest some related research aspects to be investigated for future work.
- Appendix (A) gives more information about solar energy basics; such as solar radiations, time calculation, solar angles and extraterrestrial solar radiation calculations.



- Appendix (B) contains more details about various software engineering activates, system models, system testing and artificial neural network models.
- Appendix (C) contains a programing code for some implemented functions which have been developed in this study.

## **NOTICE**

**THE OBTAINED RESULTS  
FROM THIS THESIS CAN BE  
FOUND IN THE PUBLISHED  
PAPERS AS MENTIONED  
ABOVE.**

ARABIC THESIS

SUMMARY

## ملخص الرسالة

فى الحقيقة، لعلوم الحاسب دوراً هاماً فى جميع مجالات المعرفة، حيث لم يعد هناك حقل من حقول المعرفة إلا ولعلوم الحاسب دور كبيراً فيه. العديد من المشاكل فى المجالات المختلفة يمكن حلها على نحو فعال بإستخدام علوم الحاسب. فعلوم الحاسب لدية القدرة على نمذجة وتحليل المشاكل، كذلك وضع الحلول والتأكد من صحتها. أيضاً، مقارنة الأساليب والنماذج المختلفة وصولاً للحل الأمثل.

وفى هذا الصدد، تم توظيف علوم الحاسب فى هذه الدراسة من أجل حل واحدة من أهم المشاكل فى مجال الطاقة الشمسية؛ ففى أنظمة الطاقة الشمسية؛ حيث يُعد توافر معلومات دقيقة لبيانات الإشعاع الشمسى المفتاح الرئيس لتقييم الطاقة الشمسية المتوفرة فى مكان ما على سطح الكرة الأرضية ، كما تعد المدخل الرئيس للتطبيقات المتنوعة للطاقة الشمسية. ونظراً لنقص قياسات الإشعاع الشمسى ، تم اقتراح نماذج عديدة فى دول كثيرة حول العالم للتنبؤ بالإشعاع الشمسى.

لذا، فإن هذه الدراسة تقوم بتوظيف نماذج الشبكة العصبية الاصطناعية (ANN) لتقدير الإشعاع الشمسى الكلى الساقط على الأسطح الأفقية. أيضاً، تم مقارنة أداء نماذج الشبكة العصبية (ANN models) بأداء النماذج التجريبية المختلفة ( Empirical models ) (السابق تقديمها فى الدراسات السابقة، النماذج التى تم تطبيقها فى هذه الدراسة، النماذج التى تم إقتراحها فى هذه الدراسة).

بالإضافة الى ذلك، تم توظيف الأنشطة المختلفة لهندسة البرمجيات ( Software Engineering Activities ) (توصيف، التصميم، التطوير، التحقق والإختبار) لتطوير برنامج كمبيوتر لتقدير الإشعاع الشمسى الكلى الساقط على الأسطح الأفقية لأى مكان فى مصر، إعتماًداً على إستخدام أدق النماذج الشمسية فى هذه الدراسة. أيضاً، تم إستخدام هذا البرنامج فى تحليل وإمداد البيانات المناخية الأساسية لتصميم أنظمة الطاقة الشمسية المختلفة. تم تطوير هذا البرنامج الحاسوبى بإستخدام لغة البرمجة C#.

ووفقاً للنتائج التى تم الحصول عليها، فإن أداء الشبكات العصبية الاصطناعية (ANN models) التى تم بنائها فى هذه الدراسة لديها تقدير جيد جداً للإشعاع الشمسى

الكلية. وعلى الجانب الآخر، وفقاً للنتائج المتحصلة عليها لأداء للنماذج التجريبية المختلفة (Empirical models) التي تم استخدامها في هذه الدراسة تم التعرف على النماذج الأكثر دقة في حساب الإشعاع الشمسي الكلية على الأسطح الأفقية.

علاوة على ذلك، أداء النماذج الشمسية المقبولة من النماذج المقترحة في هذه الدراسة والمعتمدة فقط على معرفة درجة الحرارة لحساب المتوسط الشهري للإشعاع الشمسي الكلية اليومي على الأسطح الأفقية أكثر دقة بالمقارنة بالأداء النماذج الشمسية الأخرى. وتمتاز هذه النماذج كونها تعتمد على بيانات درجة الحرارة والتي تعتبر أكثر البيانات المناخية توفراً ويتم قياسها في كل المواقع في جميع أنحاء العالم، كما يمكن اعتبارها بديلاً للنماذج الشمسية المعتمدة على مدة سطوع الشمس كونها الأكثر إنتشاراً لدقتها والتي لا يمكن تطبيقها في الكثير من المواقع لعدم توفر بيانات مدة سطوع الشمس. كذلك، النموذج المحلي والعالم للنموذج الشمسي الأكثر دقة من بين هذه النماذج المقترحة التي تم دراستها لديهم أداء أفضل من النماذج الشمسية الحالية المعتمدة على مدة سطوع الشمس (المنشورة في مجلات علمية) ولا سيما في المواقع الساحلية حيث التقديرات الغير دقيقة من النماذج الأخرى.

أيضاً، تم مقارنة الأداء لأفضل نموذج شمسي من النماذج التجريبية في هذه الدراسة مع أداء أفضل نموذج شبكة عصبية اصطناعية (ANN model) من النماذج التي تم بنائها في هذه الدراسة. وأظهرت النتائج أن كل من النموذجين الأدق لديهم تقدير ممتاز للإشعاع الشمسي الكلية على الأسطح الأفقية وأنهم متقاربين جداً في الأداء، وأن ANN model لديه الأداء الأفضل.

إن النتائج المعروضة في هذا الدراسة من الأهمية بمكان لإستخدامها في الحصول على تقديرات سريعة ودقيقة للإشعاعات الشمسية لإستخدامها في التطبيقات المختلفة للطاقة الشمسية. أيضاً، النماذج الحاسوبية وبرنامج الحاسوب الذي تم تطويرهم في هذا العمل يمكن إستخدامها كأساس لأي برنامج حاسوبي خاص بأنظمة الطاقة الشمسية المختلفة.

تحتوي هذه الرسالة على ستة (٦) فصول وثلاث ملاحق متضمنة مراجع عددها ١٠٠ مرجعاً، وهي كالتالي :

**الفصل الأول :** بعنوان "مقدمة" ويقدم لموضوع الدراسة والهدف منها وكذلك أهميتها، كما يعرض مخطط الرسالة.

**الفصل الثاني :** بعنوان "معلومات أساسية والدراسات السابقة" ويتضمن المعلومات الأساسية لموضوع الدراسة. مشتملاً أيضاً الدراسات السابقة المرتبطة بموضوع الدراسة.

**الفصل الثالث :** بعنوان "البيانات والنماذج الرياضية" ويشتمل هذا الباب كل من البيانات والنماذج الرياضية للنماذج الشمسية المختلفة التى تم إستخدامها فى الدراسة. أيضاً يعرض بناء نموذج الشبكة العصبية الاصطناعية التى تم إستخدامها فى الدراسة. بالإضافة الى ذلك طريقة تقييم الأداء للنماذج الشمسية المختلفة.

**الفصل الرابع :** بعنوان "النتائج والمناقشة" وفيه تم عرض كافة النتائج المستخلصة من الدراسة؛ متضمنة نتائج الأداء للنماذج الشمسية التجريبية ونتائج الأداء لنماذج الشبكات العصبية الاصطناعية (ANN). أيضاً التعرف على أفضل نموذج شمسي خاص بموقع الدراسة من بين النماذج التى تم دراستها. أيضاً، عرض نتائج مقارنة الاداء لكل من النماذج الشمسية التجريبية ونماذج الشبكة العصبونية (ANN).

**الفصل الخامس :** بعنوان "تطوير البرنامج الحاسوبى" وفيه تم إستعراض تحليل وتصميم النظام الحاسوبى الذى تم برمجته وتطويره فى هذه الدراسة، أيضاً الأدوات ولغة البرمجة المستخدمة في تطوير النظام. الى جانب ذلك، يعرض الخصائص والمميزات لهذا البرنامج الحاسوبى الذى تم برمجته وتطويره للتقدير الإشعاع الشمسى الكلى على الأسطح الأفقية، أيضاً تحليل وإمداد البيانات المناخية المختلفة الأساسية لتصميم أنظمة الطاقة الشمسية.

**الفصل السادس:** بعنوان "الخلاصات والدراسات المستقبلية" ويستعرض أهم النتائج والتوصيات التى توصلت لها الدراسة. كذلك وضع خطة للعمل المستقبلى لأهم النقاط التى رأتها الدراسة لئلا تستكمل فيما بعد.

**الملحق (A) :** بعنوان "معلومات أساسية عن الطاقة الشمسية" ويتضمن المعلومات الأساسية الخاصة بالطاقة الشمسية؛ كالإشعاع الشمسى و كيفية إحتساب الزوايا الشمسية المختلفة و حساب الوقت (المحلى/الشمسى) ، بالإضافة الى كيفية إحتساب الشمسى الكلى الخارجى.

**الملحق (B) :** بعنوان "معلومات أساسية عن هندسة البرمجيات والشبكات العصبية الاصطناعية" ويقدم تفاصيل أكثر للشبكات العصبية الاصطناعية وبرمجة وتطوير الأنظمة. وفيه تم مناقشة الأنشطة المختلفة لهندسة البرمجيات والنماذج المختلفة للأنظمة وإختبار الأنظمة، أيضاً عرض نماذج المختلفة للشبكات العصبية المختلفة.

**الملحق (C) :** بعنوان "الأكواد البرمجية" ويتضمن الأكواد البرمجية لبعض الدوال التي تم بنائها وتطويرها في الدراسة.

من الجدير بالذكر انه تم استخراج عدد أربعة (٤) أبحاث من هذه الدراسة حيث تم نشر بحثين منها والإثنين الآخرين تحت المراجعة في مجلات عالمية.

## قائمة النشر

الناشر	المجلة	الحالة	البحث
Elsevier	Applied Energy	Published	New Temperature-based Models for Predicting Global Solar Radiation
AENSI	Advances in Natural and Applied Sciences	Published	Investigating the performance of different models in estimating global solar radiation
Elsevier	Journal of Atmospheric and Solar-Terrestrial Physics	Accepted with Revision	Performance Assessment of Different Day-of-the-Year-based Models for Estimating Global Solar Radiation - Case Study: Egypt
Taylor & Francis	International Journal of Green Energy	Under Review	Performance Assessment of Different Global Solar Radiation Models – Case Study: New Borg El- Arab city, Egypt





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Faculty of Science  
Department of Mathematics



جامعة الزقازيق  
كلية العلوم  
قسم الرياضيات

## “ تطبيقات علوم الحاسب في مجال الطاقة المتجددة ”

رسالة مقدمة من

محمد عبد الفتاح على أحمد

(بكالوريوس العلوم في الرياضيات وعلوم الحاسب - ٢٠٠٨م)

للحصول علي درجة الماجستير في

(علوم الحاسب) قسم الرياضيات

إلى

قسم الرياضيات

كلية العلوم

جامعة الزقازيق

٢٠١٦



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للحصول على درجة الماجستير فى

(علوم الحاسب) قسم الرياضيات

تحت اشراف

ا.م.د/ محمد السيد على

استاذ ورئيس قسم التطبيقات الهندسية للحاسب  
مدينة الأبحاث العلمية والتطبيقات التكنولوجية

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مدرس علوم الحاسب - قسم الرياضيات  
جامعة الزقازيق

## عنوان الرسالة **تطبيقات علوم الحاسب في مجال الطاقة المتجددة**

رسالة مقدمة من

**محمد عبد الفتاح على أحمد**  
 الى

قسم الرياضيات - كلية العلوم - جامعة الزقازيق

للحصول على درجة الماجستير في الرياضيات (علوم الحاسب)

وقد تمت المناقشة العلنية والموافقة العلنية عليها

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تاريخ المناقشة

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٢٠١٦ / ٨ / ٢٤