

**INVESTIGATING LIGHT PROPAGATION AND RANDOM LASING FOR
ASSESSING MILK PROPERTIES**

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UNIVERSITI SAINS ISLAM MALAYSIA

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ASSESSING MILK PROPERTIES**

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AUTHOR DECLARATION

I hereby declare that the work in this thesis is my own except for quotations and summaries which have been duly acknowledged.

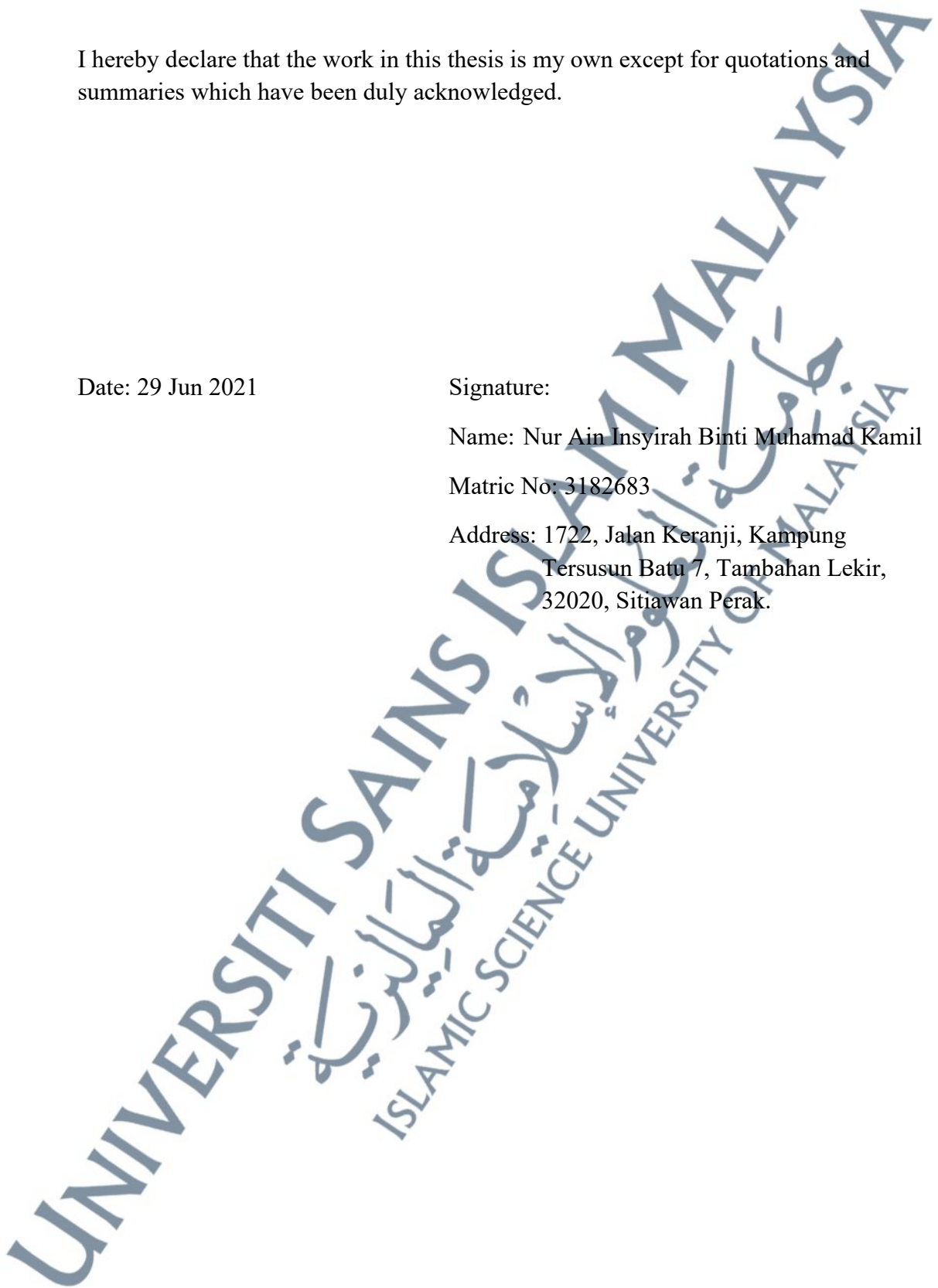
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ABSTRAK

Susu menyumbang kepada diet yang sihat kerana mengandungi komponen pemakanan seperti lemak, protein, karbohidrat, kalsium, dan vitamin. Analisis susu yang dilakukan sebelum ini melibatkan tindak balas kimia, optik, dan pembelajaran mesin, yang rumit serta memakan masa. Oleh itu, penyelidikan ini bertujuan untuk menganalisis susu berdasarkan penyebaran cahaya dan penyisipan rawak untuk menilai sifat optik susu. Keadaan susu dapat ditentukan oleh sifat optik, yang mana dapat diperhatikan melalui penyebaran cahaya. Penyebaran cahaya dalam susu dapat diamati melalui penyerapan, penuluran, pantulan, dan spektrum pendarfluor. Penyelidikan ini dibahagikan kepada tiga bahagian untuk mencapai objektif berikut: (1) untuk menyelidiki dan membandingkan penyebaran cahaya dalam susu menggunakan pelbagai spektrometer, (2) untuk menganalisis kualiti susu setelah penapaian menggunakan teknik spektrometri dan (3) untuk memodelkan laser rawak berdasarkan penyebaran cahaya dalam pelbagai jenis susu. Bahagian pertama memberi tumpuan kepada membandingkan penyebaran cahaya pada susu menggunakan teknik infra-merah dekat (NIR), terlihat (VIS) dan Fourier transform infrared (FTIR). Tiga kaedah spektrometri yang berbeza digunakan untuk menganalisis kandungan lemak susu berdasarkan spektrum serapan dan penuluran. Sampel susu penuh krim menunjukkan penyerapan tertinggi kerana kandungan zarah lemak yang lebih tinggi berbanding yang lain. Kiraan foton yang lebih tinggi dapat dianggarkan melalui pemodelan Monte Carlo. Bahagian kedua menganalisis kualiti susu selepas penapaian menggunakan spektrometer VIS-NIR. Susu disimpan dalam suhu bilik untuk proses penapaian. Hasilnya menunjukkan bahawa botol susu yang baru dibuka mempunyai penyerapan cahaya yang lebih tinggi dan penuluran cahaya yang lebih rendah daripada susu yang ditapai. Pemodelan berdasarkan teori penyerakan disediakan untuk membandingkan penyebaran cahaya dalam susu, air, dan udara. Bahagian ketiga bertujuan untuk membezakan sifat optik susu dari sumber haiwan, tumbuhan dan manusia berdasarkan penyebaran cahaya dan penyisipan rawak. Penyerapan dan pendarfluor dari pelbagai sampel susu dalam jarak gelombang antara 350 nm hingga 1650 nm diukur yang menunjukkan hasil yang berbeza untuk setiap susu, kerana kandungan lemak yang berbeza. Analisis statistik menggunakan analisis komponen utama (PCA) dilakukan untuk menganalisis kebolehpercayaan dan kesahan data serapan dan pendarfluor. Sebaliknya, laser rawak dimodelkan untuk mengkaji kesan kandungan lemak susu terhadap sifat laser rawak. Kandungan lemak yang lebih tinggi dalam susu dapat menghasilkan ambang lasing yang lebih rendah. Oleh itu, penyelidikan ini penting untuk menilai sifat optik susu. Kajian ini dapat dipertingkatkan lagi dengan membuat eksperimen penyerakan dan laser rawak.

ABSTRACT

Milk contributes to a healthy diet as it contains nutritional components such as fats, proteins, carbohydrates, calcium, and vitamins. Previous analysis of milk involves chemical reactions, optics, and machine learning, which are complicated and time consuming. Thus, this research aims to analyse milk based on light propagation and random lasing for assessing optical properties of milk. The appearance of milk can be determined by the optical properties, which can be observed through light propagation. The light propagation in milk can be observed through absorbance, transmission, reflectance, and fluorescence spectra. The research is divided into three parts in order to achieve the following objectives: (1) to investigate and compare light propagation in milk using various spectrometers, (2) to analyse milk quality after fermentation using spectrometry technique and (3) to model random laser based on light propagation in various types of milk. The first part focuses on comparing light propagation in milk using near infra-red (NIR), visible (VIS) and Fourier transform infrared (FTIR) techniques. Three different spectrometry methods are utilized to analyse the milk fat contents based on absorbance and transmittance spectra. Full milk sample shows the highest absorbance due to high fat globule content compared to others. Higher photon count can be estimated through Monte Carlo modeling. The second part analyses the milk quality after fermentation using VIS-NIR spectrometer. Milk is kept in the room temperature for the fermentation process. The results show that the newly opened milk bottle has higher light absorbance and lower light transmission than the fermented milk. Modeling based on scattering theory is provided to compare light propagation in milk, water, and air. The third part aims to differentiate optical properties of milk from animal, plant and human sources based on light propagation and random lasing. The absorbance and fluorescence of various milk samples in the wavelength range 350 nm to 1650 nm are measured which shows the different results for each milk, due to different fat content. Statistical analysis using principal component analysis (PCA) is done to analyse the reliability and the validity of the absorbance and fluorescence data. On the other hand, random laser is modeled to study the effects of milk fat content on properties of random lasers. Higher fat content in milk can produce lower lasing threshold. Therefore, this research is important to assess optical properties of milk. This study can be further enhanced by setting up scattering and random laser experiments.

امللخص

ساهم الحليب في اتباع نظام غذائي صحي لاحتوائه على مكونات غذائية مثل الدهون والبروتينات والكربوهيدرات والكالسيوم والفيتامينات. يتضمن التحليل السابق للحليب التفاعلات الكيميائية والبصريات والتعلم الآلي ، وهو أمر معقد ويستغرق وقتًا طويلاً. وبالتالي ، يهدف هذا البحث إلى تحليل الحليب بناءً على التكاثر الخفيف والليزر العشوائي لتقدير الخواص البصرية للحليب. يمكن تحديد مظهر الحليب من خلال الخصائص البصرية التي يمكن ملاحظتها من خلال انتشار الضوء. يمكن ملاحظة انتشار الضوء في الحليب من خلال أطراف الامتصاص والانتقال والانعكاس والفلورة. ينقسم البحث إلى ثلاثة أجزاء من أجل تحقيق الأهداف التالية: (1) فحص ومقارنة الانتشار الخفيف في الحليب باستخدام مقاييس طيفية مختلفة ، (2) لتحليل جودة الحليب بعد التخمير باستخدام تقنية قياس الطيف ، (3) لنمذجة الليزر العشوائي. على أساس التكاثر الخفيف في أنواع مختلفة من الحليب. يركز الجزء الأول على مقارنة انتشار الضوء في الحليب باستخدام تقنيات الأشعة تحت الحمراء القريبة (NIR) ، وتقنيات الأشعة تحت الحمراء المرئية (VIS) وتحويل فورييه (FTIR). يتم استخدام ثلاث طرق مختلفة لقياس الطيف لتحليل محتويات دهون الحليب بناءً على أطراف الامتصاص والنفاذية. تظهر عينة الحليب الكاملة أعلى امتصاص بسبب ارتفاع محتوى الكريات الدهنية مقارنة بالآخرين. يمكن تقدير عدد الفوتون الأعلى من خلال نمذجة مونت كارلو. الجزء الثاني يحلل جودة الحليب بعد التخمير باستخدام مطياف VIS-NIR. يُحفظ الحليب في درجة حرارة الغرفة لعملية التخمير. أظهرت النتائج أن زجاجة الحليب التي تم فتحها حديثًا تتمتع بقدرة أعلى على امتصاص الضوء وانخفاض انتقال الضوء من الحليب المخمر. يتم توفير النمذجة القائمة على نظرية التشتت لمقارنة انتشار الضوء في الحليب والماء والهواء. الجزء الثالث يهدف إلى التمييز بين الخصائص البصرية للحليب من المصادر الحيوانية والنباتية والبشرية على أساس التكاثر الخفيف والليزر العشوائية. يتم قياس الامتصاص والفلور لعينات الحليب المختلفة في نطاق الطول الموجي 350 نانومتر إلى 1650 نانومتر مما يدل على النتائج المختلفة لكل حليب ، بسبب محتوى الدهون المختلف. يتم إجراء التحليل الإحصائي باستخدام تحليل المكون الرئيسي (PCA) لتحليل موثوقية وصحة بيانات الامتصاص والفلورة. من ناحية أخرى ، تم تصميم نموذج الليزر العشوائي لدراسة تأثير محتوى دهون الحليب على خصائص الليزر العشوائي. يمكن أن ينتج عن ارتفاع نسبة الدهون في الحليب عتبة ليزر أقل. لذلك ، فإن هذا البحث مهم لتقييم الخصائص البصرية للحليب. يمكن تحسين هذه الدراسة عن طريق إجراء تجارب ليزر عشوائية ونثرية.

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LIST OF ABBREVIATIONS

IR	Infra-Red
VIS	Visible
NIR	Near-Infrared
UV	Ultra Violet
UV-VIS	Ultra Violet- Visible
VIS-NIR	Visible-Near Infrared
FTIR	Fourier Transform Infra-Red
PCA	Principal Component Analysis
OAM	Orbital Angular Momentum
POF	Plastic Optical Fiber
RI	Refractive Index
SCS	Somatic Cell Check
MUN	Milk Urea Nitrogen
MIRS	Mid-Infrared Spectroscopy
FCM	Flow Cytometry
ICP-OES	Inductively Coupled Plasma-Optical Emission Spectrometry
AMS	Alpha Magnetic Spectrometer
oaTOF	orthogonal-acceleration Time-Of-Flight
DART	Direct Analysis in Real Time
EDTA	Ethylenediaminetetraacetic acid
IoT	Internet of Things
MEMS	Micro-Electrochemical Systems
RMSE	Root-mean-square error
UHT	Ultra-High Temperature
FDTD	Finite Different Time Domain
FEM	Finite Element Modeling
FBGs	Fiber Bragg Gratings
BM	Breast Milk