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# INTEGRATION OF INTERNET OF THINGS AND MACHINE LEARNING FOR LOGISTICS 4.0 OF FRESH MANGO AGROINDUSTRY

SARI INTAN KAILAKU



AGROINDUSTRIAL ENGINEERING  
GRADUATE SCHOOL  
IPB UNIVERSITY  
BOGOR  
2024



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## SUMMARY

SARI INTAN KAILAKU. Integration of Internet of Things and Machine Learning for Logistics 4.0 of Fresh Mango Agroindustry. Supervised by YANDRA ARKEMAN, Y ARIS PURWANTO, and FAQIH UDIN.

Agroindustry serves as a vital economic driver by connecting farming, fresh handling and processing industries, and end consumers through an interconnected value chain. The advancements in agroindustrial engineering have expanded markets, thereby amplifying the logistics activities. However, maintaining the quality of perishable goods, like fresh fruit, during long-distance transportation remains a significant challenge in Indonesia due to inadequate postharvest handling and transportation conditions.

Mangoes, a key horticultural product in Indonesia, are traded both domestically and internationally. Enhancing the quality assurance of these mangoes is crucial for increasing their market competitiveness. Real-time quality monitoring using Information and Communication Technology (ICT) and Internet of Things (IoT) has been identified as a solution to this issue. Moreover, machine learning can predict product quality and provide critical data for stakeholders to make informed logistics and quality-related decisions. The integration of IoT and machine learning can develop an accurate real-time quality monitoring system, boosting the competitiveness of Indonesia's mango industry and reducing postharvest losses.

This study aims to integrate IoT architecture with machine learning techniques to develop an intelligent system for the long-distance transportation of fresh mangoes, supporting the implementation of Logistics 4.0. The specific objectives are: (1) to investigate the respiration pattern and quality characteristics of mangoes during storage, (2) to model and classify mango maturity based on quality characteristics affected by storage conditions and duration, (3) to develop machine learning model for mango maturity prediction, (4) to create IoT architecture for real-time monitoring of long-distance mango transportation, and (5) to design an IoT-based information system for mango transportation. The proposed solutions include developing real-time monitoring of transportation conditions and real-time maturity prediction. This involves creating an information system, machine learning algorithms, IoT architecture and device, along with a model for maturity changes. Machine learning algorithm, IoT device, and information system's performances were measured to ensure scalability.

The research begins with system identification, followed by simultaneous modeling of maturity levels, IoT device engineering, and application development. A Deep Learning model is trained using datasets from laboratory observations of mango quality changes during storage and IoT-monitored environmental conditions. Transportation simulations validate the system's performance in both land and inter-island transportation.

Findings indicate that mangoes with 85% maturity are optimal for long-distance transportation. A classification model for mango maturity based on quality attributes is developed. This model, utilizing changes in physicochemical parameters during storage, achieves over 95% accuracy in predicting maturity level changes during transportation.



IoT devices successfully collect, record, and transfer transportation data to the database and information system. The information system provides accessible transportation information and maturity predictions to stakeholders via a web-based application.

This dissertation exemplifies a compelling Artificial Intelligence of Things (AIoT) use case by integrating IoT architecture with machine learning techniques to tackle the logistics and transportation challenges of perishable goods. The IoT component involves sensors and devices that monitor environmental conditions, collecting real-time data transmitted to a central database. Machine learning models then analyze this data to predict mango maturity and quality changes during transportation, providing timely alerts to stakeholders for informed decision-making. This AIoT integration not only enhances quality monitoring accuracy but also optimizes the supply chain, reducing postharvest losses and improving market competitiveness. The project's success highlights the transformative potential of AIoT in revolutionizing traditional agroindustries and driving sustainable economic growth.

The implications of this study are significant for the agriculture sector, particularly in enhancing logistics performance and product quality assurance. Accurate prediction of agricultural product maturity levels can revolutionize logistics and inventory management by optimizing distribution, thus reducing losses. Future research should focus on improving predictive models by incorporating additional factors, exploring the effects of varying storage conditions, and expanding the dataset to include a wider range of fruit varieties. Real-time predictive analytics present a promising opportunity to enhance the agricultural value chain. The system's autonomy can be improved by integrating actuators to manage environmental conditions dynamically, and by developing advanced IoT architectures that include robust, scalable systems with high-precision sensors for comprehensive real-time monitoring. The incorporation of intelligent decision-making applications will further optimize logistics processes and resource management. Additionally, adopting blockchain technology could revolutionize the mango supply chain by ensuring traceability and transparency, thus improving quality assurance and stakeholder trust. Establishing standardized data formats and improving machine learning algorithms will enhance the system's efficiency and adaptability, making it a model for sustainable practices in agricultural logistics.

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## RINGKASAN

SARI INTAN KAILAKU. Integrasi *Internet of Things* dan *Machine Learning* untuk Logistik 4.0 pada Agroindustri Mangga Segar. Dibimbing oleh YANDRA ARKEMAN, Y ARIS PURWANTO, and FAQIH UDIN.

Agroindustri berfungsi sebagai penggerak perekonomian yang penting dengan menghubungkan pertanian, industri pengolahan dan penanganan segar, serta konsumen akhir melalui rantai nilai yang saling berkaitan. Kemajuan dalam teknik agroindustri telah memperluas pasar, sehingga memperkuat kegiatan logistik. Namun, menjaga kualitas produk yang mudah rusak, seperti buah segar, selama pengangkutan jarak jauh masih menjadi tantangan besar di Indonesia karena kondisi penanganan dan pengangkutan pascapanen yang tidak memadai.

Mangga, salah satu produk hortikultura utama di Indonesia, diperdagangkan baik di dalam negeri maupun internasional. Meningkatkan jaminan mutu mangga sangat penting untuk meningkatkan daya saing pasar. Pemantauan mutu secara *real-time* menggunakan Teknologi Informasi dan Komunikasi (TIK) dan *Internet of Things* (IoT) merupakan solusi untuk masalah ini. Selain itu, *machine learning* dapat memprediksi mutu produk dan menyediakan data penting bagi pemangku kepentingan untuk membuat keputusan logistik yang tepat. Integrasi IoT dan *machine learning* dapat mengembangkan sistem pemantauan mutu yang akurat secara *real-time*, meningkatkan daya saing industri mangga Indonesia, dan mengurangi kerugian pascapanen.

Penelitian ini bertujuan untuk mengintegrasikan arsitektur IoT dengan teknik *machine learning* untuk mengembangkan sistem cerdas transportasi jarak jauh buah mangga segar, mendukung implementasi Logistics 4.0. Tujuan spesifik penelitian antara lain: (1) mengetahui pola respirasi dan karakteristik mutu mangga selama penyimpanan, (2) memodelkan dan mengklasifikasikan kematangan mangga berdasarkan karakteristik mutu yang dipengaruhi oleh kondisi dan durasi penyimpanan, (3) mengembangkan model *machine learning* untuk prediksi kematangan mangga, (4) membangun arsitektur IoT untuk monitoring transportasi mangga jarak jauh secara *real-time*, dan (5) merancang sistem informasi transportasi mangga berbasis IoT. Solusi yang diusulkan mencakup pengembangan pemantauan kondisi transportasi secara *real-time* dan prediksi kematangan secara *real-time*. Hal ini melibatkan pengembangan sistem informasi, algoritma *machine learning*, arsitektur dan perangkat IoT, serta model untuk perubahan kematangan. Kinerja algoritma *machine learning*, perangkat IoT, dan sistem informasi diukur untuk memastikan skalabilitasnya.

Penelitian diawali dengan identifikasi sistem, dilanjutkan dengan pemodelan tingkat kematangan secara simultan, rekayasa perangkat IoT, dan pengembangan aplikasi. Model *Deep Learning* dilatih menggunakan kumpulan data dari pengamatan laboratorium terhadap perubahan mutu mangga selama penyimpanan dan kondisi lingkungan yang dipantau oleh IoT. Simulasi transportasi memvalidasi kinerja sistem baik pada transportasi darat maupun antar pulau.

Temuan penelitian menunjukkan bahwa mangga dengan kematangan 85% optimal untuk transportasi jarak jauh. Model klasifikasi kematangan mangga berdasarkan atribut mutu telah dikembangkan. Model ini, dengan memanfaatkan



perubahan parameter fisikokimia selama penyimpanan, mencapai akurasi lebih dari 95% dalam memprediksi perubahan tingkat kematangan selama transportasi.

Perangkat IoT berhasil mengumpulkan, mencatat, dan mentransfer data transportasi ke database dan sistem informasi. Sistem informasi menyediakan informasi transportasi dan prediksi kematangan yang dapat diakses oleh pemangku kepentingan melalui aplikasi berbasis web.

Disertasi ini memberikan contoh kasus penggunaan *Artificial Intelligence of Things* (AIoT) yang menarik dengan mengintegrasikan arsitektur IoT dengan teknik *machine learning* untuk mengatasi tantangan logistik dan transportasi barang yang mudah rusak. Komponen IoT melibatkan sensor dan perangkat yang memantau kondisi lingkungan, mengumpulkan data *real-time* yang dikirimkan ke database pusat. Model *machine learning* kemudian menganalisis data tersebut untuk memprediksi kematangan mangga dan perubahan mutu selama pengangkutan, sehingga memberikan peringatan *real-time* kepada pemangku kepentingan untuk pengambilan keputusan yang tepat. Integrasi AIoT ini tidak hanya meningkatkan akurasi pemantauan mutu tetapi juga mengoptimalkan rantai pasok, mengurangi kerugian pascapanen, dan meningkatkan daya saing pasar. Keberhasilan penelitian ini menggarisbawahi potensi transformatif AIoT dalam merevolusi agroindustri tradisional dan mendorong pertumbuhan ekonomi berkelanjutan.

Implikasi dari studi ini sangat signifikan terhadap sektor pertanian, khususnya dalam meningkatkan kinerja logistik dan jaminan mutu produk. Prediksi tingkat kematangan produk pertanian yang akurat dapat merevolusi logistik dan manajemen inventaris dengan mengoptimalkan distribusi, sehingga mengurangi kerugian. Penelitian di masa depan perlu berfokus pada peningkatan model prediktif dengan memasukkan faktor-faktor tambahan, mengeksplorasi dampak dari berbagai kondisi penyimpanan, dan memperluas kumpulan data untuk mencakup lebih banyak varietas buah. Analisis prediktif *real-time* menghadirkan peluang menjanjikan untuk meningkatkan rantai nilai pertanian. Otonomi sistem dapat ditingkatkan dengan mengintegrasikan aktuator untuk mengelola kondisi lingkungan secara dinamis, dan dengan mengembangkan arsitektur IoT canggih yang mencakup sistem yang kuat dan dapat diskalagandakan dengan sensor presisi tinggi untuk pemantauan *real-time* yang komprehensif. Penggabungan aplikasi pengambilan keputusan cerdas akan lebih mengoptimalkan proses logistik dan manajemen sumber daya. Selain itu, penerapan teknologi blockchain dapat merevolusi rantai pasok mangga dengan memastikan ketertelusuran dan transparansi, sehingga meningkatkan jaminan mutu dan kepercayaan pemangku kepentingan. Selain itu, perlu penetapan format data standar dan penyempurnaan algoritma *machine learning* akan meningkatkan efisiensi dan kemampuan sistem untuk beradaptasi, menjadikannya sebuah model untuk logistik pertanian berkelanjutan.





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# INTEGRATION OF INTERNET OF THINGS AND MACHINE LEARNING FOR LOGISTICS 4.0 OF FRESH MANGO AGROINDUSTRY

SARI INTAN KAILAKU

Dissertation  
as a partial fulfillment of the requirements for a  
**Doctorate** degree in  
Agroindustrial Engineering Study Program

AGROINDUSTRIAL ENGINEERING  
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Examination Date:  
15 July, 2024

Submission Date:  
(.....)



## PREFACE

*Assalamualaikum wr wb.* All praise is due to Allah SWT, who bestows blessings, opportunities, health, and abundant grace upon the author, enabling them to be born, grow, and pursue a Doctoral degree in Agroindustrial Engineering at IPB University. The author acknowledges that this work could not have been completed without His permission and grace. Peace and blessings be upon the Prophet Muhammad SAW, who serves as a source of inspiration and motivation for individuals to strive towards becoming better and more useful in life.

The author wants to express her gratitude, appreciation, and compassion to the following:

1. Prof. Dr. Ir. Yandra Arkeman, M.Eng., Prof. Dr. Ir. Y Aris Purwanto, M.Sc., Dr. Ir. Faqih Udin, M.Si., and Dr. Ir. (the late) Ade Iskandar as Academic Supervisors for all the support, patience, and guidance during the author's journey in completing this dissertation.
2. Dr. Ir. Haryono Soeparno, M.Sc. and Prof. Dr. Endang Warsiki, S.TP, M.Si as external examiners, Prof. Dr. Ing. Azis Boing Sitanggung, S.TP, M.Sc as seminar moderator, Prof. Dr. Ir. Sutrisno, M.Agr and Dr. Elisa Anggraeni, S.TP, M.Sc. as proposal examiners, for the constructive suggestions.
3. Prof. Dr. Ir. Illah Sailah, M.S., Prof. Dr. Eng. Taufik Djatna, S.TP., M.Si., Prof. Dr. Ir. Moh. Yani, M.Eng, and Prof. Dr. Farah Fatma, S.TP., MT as Head and Secretaries of the Agroindustrial Engineering Study Program for the guidance, direction, and motivation. Also, the study program administrator, Pak Candra Agustiyadi for all the help and support.
4. Her parents, Prof. Dr. Irsal Las, MS. and Mrs. Emiwati, BA., and her parent-in-laws, Mr. (the late) Mamat Darmatin and Mrs. Ati Sariati, who have been the best role models and always give endless love and support to the author. Her sisters, sisters-and brothers-in-law, for always being there to cheer the author. Nieces and nephews who have always been the joy of the days. Beloved husband Andi Darmansyah, S.TP. and children, M. Fadeyka Ahsanfadhila and Naqiya Hafsa Fatimah who have shown incredible compassion, patience, and encouragement. All sincere love and gratitude for you, may you all always under the protection of Allah SWT.
5. The Ministry of Agriculture, particularly Indonesian Agency of Agricultural Research and Development, now Indonesian Agency for Agricultural Instrument Standardization, and Indonesian Center for Agricultural Postharvest Research and Development, now Indonesian Center for Agricultural Postharvest Instrument Standards Testing, for the guidance and support for the author's career as researcher and Master Degree and Doctorate scholarships.
6. The leaders, management, and staffs of National Research and Innovation Agency (BRIN) for the Doctorate scholarship and warm welcome during the institutional transformation from Ministry R&D to BRIN.
7. PT. Laris Manis Utama's staffs and fellow research team of Rispro LPDP Logistics 4.0, especially Dr. Ali Khumaidi, Listiana Ningrum, MT., Ayu Putri Ana, M.Si., and Mas Baskara for the companionship and support, and Dr. Heru Sukoco and Dr. Sony H Wijaya for the support and guidance during the project. Technicians and analysts of the Postharvest Research and Development Lab of ICAPRD for the help, support, and companionship.

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8. All members of BRAIN-IPB scientific cluster, especially the management team: Dr. Irman Hermadi, Hendri Wijaya, M.Si., Nizmah Jatisari Hidayah, MP., and Verry Surya Hendrawan, MM. for the support, knowledge sharing, and companionship.
9. Afifah Nur Arfiana, MT., Achmad Mujib, MT., Muslih Hakim, MT., and IGM Teddy Pradana, MT. who have been very patiently and sincerely helping and supporting since the very beginning. Efri Yulistika, S.TP., MT., and Firman Arief Soejana, S.T., MT. for the full support towards the finalization of the dissertation.
10. Dr. drh. Aulia Evi Susanti, M.Sc and Rima Purnamayani, S.P., M.Si for the warm friendship and cheerfulness during the Doctoral program journey together, as well as members of the Asaroh team for the friendship and encouragement.
11. Fellow researchers and staffs at the Research Center for Agroindustry, BRIN especially Research Group for Agroindustrial System and Management, and fellow colleagues at the Indonesian Center for Agricultural Postharvest Research and Development, for encouragement and support.
12. All classmates and teammates in Agroindustrial Engineering Doctoral and Magister Program 2020, student guidance groups, graduate students' organizations: IPB Universitas Graduate Students Forum (Forum Wacana) Kabinet Excellent, IAARD Student-Staffs Forum (Formalita) 2020-2021, Agroindustrial Engineering Graduate Students Forum (Formatip) 2020-2023, and all of IPB University friends.

Hopefully, this dissertation will be valuable for the community and the advancement of science.

Bogor, August 2024

*Sari Intan Kailaku*

## CONTENTS

LIST OF TABLES	xv
LIST OF FIGURES	xv
LIST OF APPENDICES	xvii
I INTRODUCTION	1
1.1 Background	1
1.2 Problem Formulation	4
1.3 Objectives	5
1.4 Benefits	5
1.5 Scope	6
1.6 Novelty	6
II LITERATURE REVIEW	7
2.1 Mango Characteristics and Respiration Pattern	7
2.2 Postharvest Losses and Fresh Fruit Quality Monitoring	8
2.3 Fruit Quality Assessment	11
2.4 Internet of Things and Machine Learning for Quality Monitoring and Supply Chain Management	12
2.5 Research Gap Analysis	16
2.6 Digital Business Model Innovation	19
III METHODOLOGY	20
3.1 Research Framework	20
3.2 Time and Location	21
3.3 Research Stages	21
3.4 System Identification	23
3.5 Laboratory Experiment	24
3.6 Mango Maturity Level Changes and Prediction Modeling	28
3.7 Internet of Things Architecture Development and Device Engineering	31
3.8 Information System and Application Development	33
3.9 Transportation Simulation	35
3.10 Research Summary	36
IV RESULTS AND DISCUSSION	38
4.1 System Identification	38
4.2 Mango quality and maturity characterization and changes	46
4.3 Mango Maturity Level Changes and Prediction Model	57
4.4 Internet of Things Architecture Development and Device Engineering	68
4.5 Information System and Application	73
4.6 Transportation Simulation	78
4.7 AIoT and Road Map for Future Development	83
V CONCLUSION AND RECOMMENDATION	85
5.1 Conclusion	85
5.2 Recommendation	86
REFERENCES	89
APPENDICES	104
BIOGRAPHY	112



## LIST OF TABLES

1	Non-destructive methods to determine particular quality characteristics of fruits and vegetables	12
2	Maturity level (harvest age) classification	25
3	Datasets used in modeling	29
4	Confusion matrix for the calculation of precision, recall, and accuracy of a machine learning process (Santra dan Christy 2012)	31
5	Summary of the methodology and expected output of the study	36
6	The requirements of stakeholders	43
7	Quality characteristics of mango after harvest in different harvest age (n = 105)	50
8	Recommended mango harvest age for long-distance transportation based on distance and transportation type, shipment from Surabaya, East Java	56
9	The maturity level changes during storage study	62
10	Confusion matrix of the maturity level prediction model	68
11	Power consumption during transportation simulation	71
12	The feature of the web-based and mobile application	77
13	The traceability matrix of the system requirements and fulfillment	77

## LIST OF FIGURES

1	(a) changes in the CO <sub>2</sub> release rate of mango cv. Banganapalli when packed in air-tight glass bottles and stored at different temperatures; (b) changes in the O <sub>2</sub> consumption rate of mango cv. Thothapuri when packed in air-tight glass bottles and stored at different temperatures (Devanesan et al. 2012)	8
2	Simulation of strawberry supply chain to determine the critical supply chain steps and the impact of each step on the postharvest loss of strawberry (Kelly et al. 2019).	10
3	The architecture of simple Neural Network (left) and Deep Learning Neural Network (right) (Anonym 2021)	16
4	The network (a) and density (b) visualization of the bibliometric analysis	17
5	Research framework	20
6	The components of the intelligent monitoring system of mango long-distance transportation	21
7	Work Breakdown Structure (WBS) of the study	22
8	Research stages	23
9	Matters of concern in requirement analysis	23
10	Mango samples in long-distance transportation packaging	26
11	Laboratory experiment stages	26
12	Inter-island and inter-province distribution in the Indonesian mango supply chain. Remarks: the mango image shows the starting point of delivery as a case in the study, i.e., East Java province.	28



13	Flow chart of model development of maturity level changes and prediction modeling	29
14	The development of Internet of Things architecture	32
15	Prototype design (modified from Mujib (2021))	33
16	Development of information system	35
17	Transportation simulations	36
18	The existing system environment of fresh mango supply chain with long-distance transportation	39
19	The existing business process model of mango long-distance transportation	41
20	System entity diagram of IoT-based quality monitoring system	42
21	The Digital Business Ecosystem	44
22	The designed business process model for mango long-distance transportation with quality monitoring system	45
23	The Use Case Diagram	46
24	Climacteric rise of mango with different harvest ages as shown by CO <sub>2</sub> (a) and ethylene (b) production	48
25	Summary of storage temperature (a) and relative humidity (b) as recorded by IoT-based real-time monitoring system.	49
26	Total soluble solids (a) and acidity (b) of mango cv. Arumanis with a harvest age of 105 days after flowering during storage in different storage temperatures.	51
27	Firmness (a) and dry matter concentration (b) of mango cv. Arumanis with a harvest age of 105 days after flowering during storage in different storage temperatures.	53
28	Weight loss of mango cv. Arumanis with a harvest age of 105 days after flowering during storage in different storage temperatures.	55
29	Determination of $k$ value in K-Means clustering; silhouette plots (a), silhouette scores (b), and elbow method	61
30	Maturity levels based on quality parameters as clustered by K-Means clustering algorithm	62
31	Network architecture for the final maturity level prediction model for mango	63
32	Dataset format of maturity level clustering and classification (left) and dataset obtained from IoT device during storage study (right)	64
33	Data exploration (above: ambient temperature storage, below: cold storage) during preprocessing	65
34	Dataset developed for data training (above) and after the rules formation and data imputation (below)	65
35	Final dataset for model development	66
36	Deep Learning model architecture for mango maturity level prediction	67
37	Model accuracy and loss during training and testing phase	67
38	System architecture for real-time monitoring of storage conditions using Internet of Things (IoT) sensors (modified from Jagtap and Rahimifard 2019)	69
39	First design and prototype of IoT device (IoT device 1.0).	70
40	The prototype of IoT device and the installation for the first transportation simulation (IoT device 2.1).	70

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41	The design (above) and prototype (below) of improved IoT device for the inter-island simulation (IoT device 2.2)	71
42	The design (above) and prototype (below) of improved IoT device for the inter-island simulation (IoT device 2.3).	72
43	The flow of data and material in the system	73
44	The “Set Departure” menu as trigger to the maturity prediction	74
45	The “Delivery Monitoring” list	75
46	Example of monitoring report retracted from the web application	75
47	The UI design of mobile application	76
48	Inspection and measurement of the placement of IoT devices inside truck before transportation simulation	78
49	Condition of the IoT devices arrived in Surabaya	79
50	The installation of IoT devices and the samples in transportation simulation	79
51	The destructive and non destructive analysis for maturity level of mango after transportation	80
52	Inter-island transportation simulation from Surabaya to Balikpapan. (a) sortation using portable NIR; (b) destructive measurement of quality parameters; (c) IoT devices; (d) placement of mango boxes in 40 ft container; (e) placement of IoT devices on containers.	81
53	Temperature (above) and relative humidity (below) during mango shipment from Surabaya to Balikpapan	81
54	Road map for future development of intelligent quality monitoring system for climacteric fruits up to implementation and policy recommendation	84

### LIST OF APPENDICES

1	Login page of the web-based application	105
2	Master data page for commodity information	106
3	Master data page for device information	107
4	Master data page for delivery information	108
5	User Management page	109
6	Users’ roles	110
7	Users’ roles access setting	111



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