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Contents

Article

5 Probabilistic Rationale of Actions for Artificial Intelligence Systems Operating in Uncertainty Conditions
Andrey I. Kostogryzov

24 School Debit Transaction Using Fingerprint Recognition System
Wai Kit Wong, Thu Soe Min, Shi Enn Chong

38 Using the CVP Traffic Detection Model at Road-Section Applies to Traffic Information Collection and Monitor - the Case Study
Shing Tenqchen, Yen-Jung Su, Keng-Pin Chen

44 Application of Feature Curves and Shape Blending on Yacht Designing
Shih-Wen Hsiao, Jeng-Horng Chen, Ting-An Yeh

Review

1 The Comparison of Current Development, Technology and Governments’ Attitudes of Driverless Car at Home and Abroad
Chuyi Zhang

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REVIEW

The Comparison of Current Development, Technology and Governments’ Attitudes of Driverless Car at Home and Abroad

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ABSTRACT
Driverless car, as a direction for future automobile development, greatly improves the efficiency and safety of the traffic system. It’s one of the most popular technical fields. In recent years, driverless car has developed rapidly. The related development is concerned by governments, businesses, consumers and stakeholders widely, and most of countries have been actively studying this technology. This paper first introduces the current development of driverless car at home and abroad. Besides, the basic technologies of driverless car are briefly analyzed. In addition, the author compares the American government’s attitudes with Chinese government’s attitudes towards driverless car. Specifically, the article makes an analysis of contents of literature and periodicals at home and abroad and policies and documents which have already been published. The analysis shows that there is no great difference between the attitudes of Chinese and American governments. Both of two governments actively support the development of driverless car. Finally, this paper expounds the development direction of the driverless car field in future by dividing into two categories through road conditions: automatic driving on expressways and automatic driving in cities.

1. Introduction

A driverless car is a vehicle that is capable of sensing its environment and navigating without human input. Driverless cars use a variety of techniques to detect their surroundings, such as radar, laser light, computer vision, GPS, IMU and so on. The potential benefits of driverless cars include reducing mobility and infrastructure costs, increasing safety, increasing mobility, increasing customer satisfaction and reducing crime [1]. In recent years, driverless cars have been developing rapidly. The National Highway Traffic Safety Administration (NHTSA) and the Society of Automotive Engineers (SAE) have all graded automatic driving technology (see Table I), which, to a certain extent, represents the development phase of the driverless technology [2]. In China, the driverless technology has developed well with the encouragement and support of the government. Beijing, Shanghai and some other cities have promulgated the detailed rules of automatic driving road test. In 2014, Google fired a shot heard all the way to Detroit. Google’s newest driverless car had no steering wheel and no brakes. The message was clear: cars of the future will be born fully autonomous, with no human driver needed [3]. Companies, such as Uber and Waymo, are also actively testing driverless cars hoping for combining autopilot technology

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with car calling services. In Dubai, the first driverless taxi in the world was put into operation by the Dubai highway and Transport Administration (RTA) in February 28, 2018. These show that the automotive industry is undergoing a revolution. It is obvious that driverless cars are likely to be widely applied in the future, which has great certain research significance.

However, no one has investigated both of the technology and governments’ attitudes of driverless cars at home and abroad so far. There are few book resources about this topic. But there are many Internet sources and periodical sources that appear to be reliable. Contents of literature and periodicals at home and abroad and policies and documents which have already been published are analyzed.

### Table 1. Automatic Drive Classification

<table>
<thead>
<tr>
<th>Automatic Drive Classification</th>
<th>Name (SAE)</th>
<th>Main Part</th>
<th>System Scope</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Driving Operation</strong></td>
<td><strong>Peripheral Monitoring</strong></td>
<td><strong>Support</strong></td>
<td><strong>System Scope</strong></td>
</tr>
<tr>
<td>0 0</td>
<td>No Automation</td>
<td>Human Drivers</td>
<td>System</td>
</tr>
<tr>
<td>1 1</td>
<td>Driving Support</td>
<td>Human Driving System</td>
<td>Human Drivers</td>
</tr>
<tr>
<td>2 2</td>
<td>Partial Automation</td>
<td>System</td>
<td>System</td>
</tr>
<tr>
<td>3 3</td>
<td>Conditional Automation</td>
<td>System</td>
<td>System</td>
</tr>
<tr>
<td>4 4</td>
<td>Highly Automation</td>
<td>System</td>
<td>System</td>
</tr>
<tr>
<td>5 5</td>
<td>Complete Automation</td>
<td>System</td>
<td>System</td>
</tr>
</tbody>
</table>

### 3. The Development Status of Driverless Car in China

The development of domestic driverless vehicle is lagging behind compared with other developed countries.

In 1992, National University of Defense Technology developed the real driverless car in China. In 2000, the fourth generation of driverless cars developed successfully with a speed of 76km/h. In 2005, Shanghai Jiao Tong University developed the first urban driverless car. Since 2009, with the support of the National Natural Science Fund, the “China smart car future challenge”, the only competition aimed at driverless car in China, has been successfully held for eight sessions. It has played a great role in promoting the development of driverless cars in China. In 2010, the pilotless car developed by the National University of Defense Technology and FAW has realized autonomous navigation without human intervention, and can drive stably on high speed roads.

After 2013, IT giants in China and some large autonomous vehicle companies gradually joined in the field of technology development in the field of driverless vehicle. The unmanned pilot project, led by the Baidu Institute for deep learning and research, started in 2013. In 2015, Baidu realized the road test of the driverless vehicle. At the same time, it announced the establishment of the automatic driving department, and plans to complete commercialization as soon as possible. In addition, BYD and other auto companies have gradually stepped into the field of self-driving.

In 2016, Baidu Inc and Ford automobile company invested in laser radar manufacturer Velodyne, hoping to reduce the production cost of driverless car laser radar. In addition, Baidu has started to work with NVIDIA, a global graphic technology and digital media processor industry leader, to form an automatic driving platform. At
the same time, Jingdong announced that its unmanned vehicle began to enter the road test phase and planned to run the test and may be able to use it on a large scale in 2017. Didi announced that driverless car would be one of their major strategic layouts, and will soon achieve the goal of carrying a passenger car on a driverless car.

4. The Basic Technologies of Driverless Car

The most important part of driverless car is the automatic driving system, which mainly consists of three parts: environmental perception, vehicle location and navigation, and motion control. These three aspects complement each other and constitute the foundation of driverless car [8].

4.1 Environmental Perception

In the driving process, people need to observe and analyze the state of the vehicle itself, other vehicles, pedestrians, road, traffic lights and so on, which is called the perception of the traffic environment. This perception first obtains information through multi-senses, and then uses information and experience to make sense information and make decisions. Like people, driverless car also needs to perceive the environment when driving autonomously. Environmental perception, which is similar to the driver’s eyes, usually made up of camera devices, sensors, and so on. It is used to perceive the driving environment, and then to produce behavioral decisions based on the useful environmental information obtained.

4.2 Vehicle Location and Navigation

Vehicle location and navigation is similar to the driver’s map. Currently, the most commonly used technologies include magnetic navigation and visual navigation. Among them, magnetic navigation is the most mature and reliable scheme at present. The biggest advantage of magnetic navigation is that it’s not affected by natural conditions such as weather. However, magnetic navigation methods often need to bury certain navigation devices on the road, and the implementation process is cumbersome. The advantage of visual navigation is that it can prevent cars deviate from the target lane. But with low visibility caused by natural factors, the navigation system will not work. Due to the low requirement for infrastructure, visual navigation is generally recognized as the most promising location method.

4.3 Motion Control

Motion control system is similar to the driver’s brain, which is used to analyze road information. It’s based on the driving trajectory, speed planning and the current position, posture and speed of the driverless car. And then it produces control commands for the throttle, the brake, the steering wheel and the transmission lever to track the planned trajectory and send out the corresponding instructions. At present, the most commonly used method is the classical intelligent PID algorithm.

5. Governments’ Attitudes Towards Driverless Car

5.1 The United States

The United States is the leader in the development and application of driverless car in the world. The U.S. Department of Transportation (DOT) published the world’s first self-driving cars policy document Federal Automated Vehicles Policy in September 20, 2016 [7]. This policy includes the policy objectives and Taxonomy and Definitions for Terms Related to On-Road Motor Vehicle Automated Driving Systems. The previous day, President Obama introduced a new deal in Pittsburgh Post-Gazette: “Automated vehicles could change their lives. Safer, more accessible driving. Less congested, less polluted roads. That’s what harnessing technology for good can look like. But we have to get it right. That’s why my administration is rolling out new rules of the road for automated vehicles – guidance that the manufacturers developing self-driving cars should follow to keep us safe.”

5.2 China

In November 15, 2017, China’s Ministry of science and technology announced that it would rely on Baidu to build a new generation of automatic driving national innovation platform. In December 18, 2017, the Beijing Municipal Transportation Committee, the Public Security Management Bureau, the Economic Information Committee and other departments issued two guiding documents on the guidance of speeding up the road test of automatic driving vehicles and the detailed rules for the implementation of the road test management for automatic driving vehicles [9]. It’s clearly pointed out that the independent legal entity registered in China can apply for temporary driving on account of automatic driving related research and stereotype test. Beijing has taken the lead in making a complete set of laws and regulations for driverless car. To a certain extent, it supports the development and popularization of driverless car.

6. The Future Development Direction of the Driverless Car Field

The development direction of driverless car can be divid-
ed into two categories through road conditions: automatic driving on expressways and automatic driving in cities.

The driving environment and traffic signs on the freeway are relatively better, but long time driving at high speed is rather boring for drivers. The application of driverless car in this direction can solve this problem well, and also can effectively improve the efficiency and safety of traffic. In the future development, as long as driverless car completes the mark line tracking and vehicle identification function on a well structured highway, and can avoid the same track as far as possible, the full automatic driving of the highway can be achieved successfully.

In cities, there are more vehicles and people on the road. Additionally, the environment is much more complex. In the autonomous driving test which took place in Parma in July 2013, the vehicle has proven to be able to drive autonomously, without any human intervention, sharing roads with other vehicles, and manage roundabouts, intersections, priority roads, stops, tunnels, crosswalks, traffic lights, highways, and urban roads. But one of the aspects that need to be further investigated and developed is the driving efficiency and speed: the test was carried out considering safety as a priority, and the most complicated maneuvers were carried out at a reduced speed. Plus some perception problems still have to be solved: the problem of merging in large and multi-lane roundabouts, where vehicles travel at high speeds, has not been completely solved. So it still needs further technical support and research, and puts forward higher requirements for the technology.

7. Conclusions

This paper investigates the current development of driverless cars at home and abroad, analyses the basic technologies of driverless cars, compares the American government’s attitudes with Chinese government’s attitudes towards driverless cars, and expounds the future development direction of the driverless car in two ways.

The results indicate that the development of driverless cars would be the development direction of the automotive industry in the future, and plays an important role in promoting the technology innovation in automobile industry. With the development of economy, science and technology, people would use intelligent driverless cars in the near future. It is a kind of intelligent car, which combines detection, identification, judgment, decision, optimization, execution, feedback, and control function. It also can learn, summarize and improve skills. Besides, it integrates the top scientific and technological achievements such as microcomputers, green environment power system, new structure material and so on. The driverless technology at home and abroad is developing continuously, and its function and reliability are constantly improving. What’s more, further improvements are needed in the aspects of security, intelligence and regulation of driverless cars.

References

ARTICLE

Probabilistic Rationale of Actions for Artificial Intelligence Systems Operating in Uncertainty Conditions

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ABSTRACT

The approach for probabilistic rationale of artificial intelligence systems actions is proposed. It is based on an implementation of the proposed interconnected ideas 1-7 about system analysis and optimization focused on prognostic modeling. The ideas may be applied also by using another probabilistic models which supported by software tools and can predict successfulness or risks on a level of probability distribution functions. The approach includes description of the proposed probabilistic models, optimization methods for rationale actions and incremental algorithms for solving the problems of supporting decision-making on the base of monitored data and rationale robot actions in uncertainty conditions. The approach means practically a proactive commitment to excellence in uncertainty conditions. A suitability of the proposed models and methods is demonstrated by examples which cover wide applications of artificial intelligence systems.

1. Introduction

Different mathematical models and methods are applied in system analysis. System analysis is required at level of the international standards of system engineering - for example, ISO/IEC/IEEE 15288 “System and software engineering – System life cycle processes”, ISO 17359 “Condition monitoring and diagnostics of machines - General guidelines”, IEC 61508 “Functional safety of electrical/ electronic/ programmable electronic safety-related systems” etc. It is recommended for using every time across all life-cycle to analyze performance, system behaviour, feasibility, affordability, critical quality characteristics, technical risks, sensitivity for

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changes of critical parameters values etc. Artificial intelligence systems (AIS) which are understood here as systems, performing functions by logic reasoning on the base of data processing, also needs system analysis because of their complexities and uncertainty conditions.

**Note:** System is combination of interacting elements organized to achieve one or more stated purposes (according to ISO/IEC/IEEE 15288).

Considering AIS specificity there may be some scientific problems devoted to:

1. system analysis of uncertainty factors, capabilities of operation in real time, information gathering and processing, protection from unauthorized access and dangerous influences;
2. analysis of system requirements to acceptable conditions;
3. system analysis and optimization in architectural design;
4. comparative and prognostic estimations of quality, safety, interaction “user-system” and conditions, optimization of different processes, rationale of operation in uncertainty, etc.

Now there isn’t enough universal effective approach to rationale of actions for AIS operating in uncertainty conditions. In practice for each concrete case it is often used subjective expert estimations, a regression analysis of collected data, a simulation of processes [1-14]. It means, that search of new methods for advanced rationale actions of AIS and by AIS is today very important. The proposed approach is focused on probabilistic rationale of actions to operate in uncertainty conditions against existing approaches for which applied mathematical methods cover mainly information processing in the logician if …, that … and/or tracing situations by a man-operator. An application scope of this paper covers AIS supporting decision-making in intellectual manufacture (for example, in dispatcher intelligence centers) and robotics systems operating in uncertainty conditions and used to provide operation efficiency or/and increase reliability and safety (including aerial, land, underground, underwater, universal and functionally focused AIS).

The main efforts of this paper are not connected with illustrating the capabilities of AIS, but they are focused on demonstrating the applicability of original probabilistic models and methods to improve some of the existing capabilities of AIS [15-45]. For this goal by the use of these probabilistic models the next specific problems are covered:

1. the problem 1 - to rationale a rational variant for decision-making on the base of monitored data about events and conditions, and
2. the problem 2 - to rationale a robot actions under limitations on admissible risks of “failures” (according to ISO Guide 73 risk is defined as effect of uncertainty on objectives considering consequences. An effect is a deviation from the expected — positive and/or negative).

**Note:** Some relevant problems (such as the problems of robotics orientation, localization and mapping, information gathering, the perception and analysis of commands, movement and tactile, realizations of manipulations for which different probabilistic methods are also applicable) have not been covered by this work.

The proposed approach for solving AIS problems are based on theoretical and practical researches [15-45] and need to be used either in combination or in addition to existing methods which are used now in AIS. There, where it is required often prognostic system analysis or where the used approaches are not effective, the proposed probabilistic approach can be used as rational basis or alternative. The ideas of this approach may be applied also by using another probabilistic models which supported by software tools and can predict success or risks on a level of probability distribution functions (PDF). The structure of this research is shown by the Figure 1.

![Figure 1. The structure of the research](https://doi.org/10.30564/aia.v1i2.1195)
of information technologies CeBIT in Germany, noted by diplomas of the Hanover Industrial Exhibition and the Russian exhibitions of software.

2. The essence of the approach

The AIS behaviour corresponding to the rationale of actions for AIS operating in uncertainty conditions means proactive commitment to excellence. Such behaviour is based on an implementation of the next proposed interconnected ideas 1-7.

**Idea 1** is concerning the usual concept and properties of probability distribution functions (PDF) \(^{15}\) for a continuous random variable of time. PDF for a time variable \(\tau\) is nondecreasing function \(P(t)\) whose value for a given point \(t \geq 0\) can be interpreted as a probability that the value of the random variable \(\tau\) is less or equal to the time value \(t\), i.e. \(P(t) = P(\tau \leq t)\). Additionally \(P(t) = 0\) for \(t < 0\), and \(P(t) \to 1\) for \(t \to \infty\). In general case the solutions for the problems 1 and 2 are based on using concept of the probabilities of “success” and/or “unsuccess” (risk of “failure”) during the given prognostic time period \(\tau_{\text{req}}\). This probability is a value for a point \(\tau_{\text{req}}\) and is defined by created PDF.

**Idea 2.** The processes, connected with data processing, and used information should provide required AIS operation quality (because AIS is a system, performing functions by logic reasoning on the base of data processing). And corresponding probabilistic methods should appropriate for prognostic estimations.

**Idea 3.** The PDF should be presented as analytical dependence on input parameters. It needs to solve direct and inverse problems to rationale of actions in a real time of AIS operation. For example, for a simple element PDF \(P(t)\) of time \(\tau\) between losses of element integrity may be presented by analytical exponential approximation, i.e. \(P(t) = 1 - \exp(-\lambda t)\), where \(\lambda\) is frequency of failures (losses of element integrity). At the same time frequency of failures may be represented as a sum of frequencies of failures because of specific reasons for each failure type – for example, failure from “human factor” \(\lambda_1\), from hardware \(\lambda_2\), from software \(\lambda_3\) and so on. For this use case PDF may be presented as \(P(t) = 1 - \exp[-(\lambda_1 + \lambda_2 + \lambda_3 + \ldots) t]\). Then if the adequate function \(P(t)\) is built in dependence on different parameters and if admissible level for probability is given than inverse problem may be solved.

**Note.** The rationale for exponential approximation choice in practice see, for example, in \(^{28,30}\).

**Idea 4.** The PDF should be adequate, it means a dependence on several essential parameters which define AIS operation and on which “success” or “failure” of AIS operation is mainly dependent. For example the way for risks prediction based on uses only one parameter – frequency of failures \(\lambda\) - is popular today. This implies the use of corresponding exponential PDF – see Figure 2. Only one connection of the frequency of failures \(\lambda\) with random time variable \(t\) between losses of system integrity may be interpreted as the requirement: “to provide no failures during required time with probability no less than the given admissible probability \(P_{\text{adm}}\) this required time should be no more than \(\tau_{\text{req}} = 1/\lambda_{\text{adm}}\); here \(\lambda_{\text{adm}} = \ln(1-R_{\text{adm}})\).” But for AIS element it is rough and unpromising engineering estimations because capabilities of monitoring conditions and recovery of the lost element integrity are ignored. Such disregard deforms very essentially probabilistic estimations of probabilistic risk values and can’t be useful for scientific search of effective counteraction measures against different threats. Deviations from more adequate PDF estimations are very high \(^{33,44,45}\). On Figure 3 the limitations to admissible risks, fragment of exponential and an adequate PDF of time between losses of system integrity with identical frequency of system integrity losses are illustrated (in conditional units). It means more adequate PDF allows more right understanding of probabilistic AIS vision of events prediction with scientific interpretation considering situations in time line.

**Note:** System integrity is defined as such system state when system purposes are achieved with the required quality.

![Figure 2](https://example.com/fig2.png)

**Figure 2.** The possible variants of correlations for admissible risks, exponential and an adequate PDF of time between losses of system integrity with identical frequency of losses

![Figure 3](https://example.com/fig3.png)

**Figure 3.** All requirements to admissible risk are met for an adequate PDF of time between losses of system integrity

**Idea 5.** Because an AIS is a complex system and this...
AIS may be subsystem or element of comprehensive complex system. The proposed approach should allow a generation of probabilistic models for prediction of “success” or “failure” of AIS actions in uncertainty conditions. In general case an input for generated models used in real time should consider system complexity, periodical diagnostics, monitoring between diagnostics, recovery of the lost integrity for every system element and also processes, connected with data processing, and used information. As an output of such generated models adequate PDF of time $\tau$ between losses of system (subsystem, element) integrity should be produced in analytical form.

Idea 6. Input for probabilistic modeling should be formed mainly from gathered data and established specific order of AIS actions.

Idea 7. To probabilistic rationale of actions for AIS operating in uncertainty conditions the problems of optimization should be solved. Optimization should be performed in real time by defined beforehand optimization problem statement. Every time the used optimization problem statement should be appropriated for solving specific problem 1 or 2. For probabilistic rationale of actions the prognostic period should be defined so to be in time to do the given action or complex of actions on acceptable level according to optimization criterion or to perform preventive action (with which the initiation of performing an action or solving a problem is connected) or/and to recover operation capabilities (which can be lost).

For the approach implementation the next probabilistic models are proposed.

3. The Description of the Proposed Models

In general case a probabilistic space $(\Omega, B, P)$ for probabilistic modeling is created, where $\Omega$ - is a limited space of elementary events; $B$ – a class of all subspace of $\Omega$-space, satisfied to the properties of $\sigma$-algebra; $P$ – is a probability measure on a space of elementary events $\Omega$. Because, $\Omega=\{\omega_k\}$ is limited, there is enough to establish a reflection $\omega_k \mapsto p_k = P(\omega_k)$ like that $p_k \geq 0$ and $\sum p_k = 1$.

In order not to overload the reader with mathematical details, the final formulas for calculations are presented in the Appendixes A and B.

3.1 About AIS operation quality

The proposed models help to implement ideas 1 and 2.

In general case AIS operation quality is connected with requirements for reliable and timely producing complete, valid and/or, if needed, confidential information. The gathered information is used for proper AIS specificity. The abstract view on a quality of used information is presented on Figure 4.

Figure 4. Abstract explanation for a quality of used (real) information against required one

The proposed models for the estimation of information systems operation quality are described in Table A.1 of Appendix.

The main analytical models and calculated measures are the next:

1. “The model of functions performance by a complex system in conditions of unreliability of its components”;
2. “The models complex of calls processing”;
3. “The model of entering into IS current data concerning new objects of application domain”;
4. “The model of information gathering”;
5. “The model of information analysis”;
6. “The models complex of dangerous influences on a protected system”;
7. “The models complex of an authorized access to system resources”.

Risk to lose integrity (R) is an addition to 1 for probability of “success” (P), i.e. R=1-P considering consequences.

These models, supported by different versions of software Complex for Evaluation of Information Systems Operation Quality, registered by Rospatent №2000610272, may be applied and improved for solving problems 1 and 2.

3.2 About Risks Prediction for System Formalized as “Black box”

The proposed models helps to implement ideas 1, 3, 4.

In general case successful system operation (not only AIS) is connected with system counteraction against various dangerous influences on system integrity - these may be counteractions against failures, defects events, “human factors” events, etc. There are proposed the formalization for two general technologies of providing counteraction against threats: periodical diagnostics of system integrity (technology 1, without monitoring between diagnostics) and additionally monitoring between diagnostics (technology 2). As a rule these technologies are implemented by AIS.

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Technology 1 is based on periodical diagnostics of system integrity, that is carried out to detect danger sources penetration into a system or consequences of negative influences (see Figure 5). The lost system integrity can be detect only as a result of diagnostics, after which system recovery is started. Dangerous influence on system is acted step-by-step: at first a danger source penetrates into a system and then after its activation begins to influence. System integrity can’t be lost before a penetrated danger source is activated. A danger is considered to be realized only after a danger source has influenced on a system.

Figure 5. Some accident events for technology 1 (left – correct operation, right – a lose of integrity during prognostic period Treq.)

Technology 2, unlike the previous one, implies that system integrity is traced between diagnostics by operator (operator functions may be performed by a man or special AIS component or their combination). In case of detecting a danger source an operator recovers system integrity. The ways of integrity recovering are analogous to the ways of technology 1 – see Figure 6.

Figure 6. Some accident events for technology 2 (left – correct operation, right – a lose of integrity during prognostic period Treq.)

Faultless operator’s actions provide a neutralization of a danger source trying to penetrate into a system. A penetration of a danger source is possible only if an operator makes an error but a dangerous influence occurs if the danger is activated before the next diagnostic. Otherwise the source will be detected and neutralized during the next diagnostic.

It is supposed for technologies 1 and 2 that the used diagnostic tools allow to provide necessary system integrity recovery after revealing danger sources penetration into a system or consequences of influences.

The probability of correct system operation within the given prognostic period (i.e. probability of “success” - P) may be estimated as a result of use the models presented in Appendix B. Risk to lose integrity (R) is an addition to 1 for probability of correct system operation (P), i.e. R=1-P considering consequences.

3.3 About a Generation of Probabilistic Models for Complex System

The proposed method for a generation of probabilistic models helps to implement ideas 1 and 5.

The basic ideas of correct integration of probability metrics are based on a combination and development of models. For a complex systems with parallel or serial structure described there are proposed the next method to generate adequate probabilistic models [25,26,28-30]. This method uses the usual way of probability theory for independent random variables. However, given the importance to rationale the generation of new probabilistic models for complex system, the approach is described below.

Let’s consider the elementary structure from two independent parallel or series elements. Let’s PDF of time between losses of i-th element integrity is $B_i(t) = P(τ_i ≤ t)$, then:

1. time between losses of integrity for system combined from series connected independent elements is equal to a minimum from two times $τ_i$: failure of 1st or 2nd elements (i.e. the system goes into a state of lost integrity when either 1st, or 2nd element integrity is lost). For this case the PDF of time between losses of system integrity is defined by expression

   $$B(t) = P[min (τ_1, τ_2) ≤ t] = 1 - P[min (τ_1, τ_2) > t] = 1 - P(τ_1 > t)P(τ_2 > t) = 1 - [1-B_1(t)][1-B_2(t)]$$

   (1)

2. time between losses of integrity for system combined from parallel connected independent elements (hot reservation) is equal to a maximum from two times $τ_i$: failure of 1st and 2nd elements (i.e. the system goes into a state of lost integrity when both 1st and 2nd elements have lost integrity). For this case the PDF of time between losses of system integrity is defined by expression

   $$B(t) = P[τ_1 ≤ t, τ_2 ≤ t] = 1 - P[τ_1 > t]P[τ_2 > t] = 1 - [1-B_1(t)][1-B_2(t)]$$

   (2)
Applying recurrently expressions (1) – (2), it is possible to build PDF of time between losses of integrity for any complex system with parallel and/or series structure and their combinations.

An example of complex system integrating two serial complex subsystems (abstraction) is presented by Figure 7. For this integration the next interpretation of elementary events is used: complex system integrating compound components “Intellectual structure 1 and 2” is in condition “correct operation” (“success”) during given period $T_{eq}$ if during this period “AND” component “Intellectual structure 1” “AND” component “Intellectual structure 2” (both are special complex subsystems including AIS subsystems and elements) are in condition “correct operation” (“success”).

All ideas for analytical modeling complex systems are supported by the software tools “Mathematical modeling of system life cycle processes” – “know how” (registered by Rospatent №2004610858), “Complex for evaluating quality of production processes” (registered by Rospatent №2010614145) and others [46-51].

3.4 About Data Forming for Probabilistic Modeling

The proposed practical way to data forming helps to implement idea 6.

For each critical parameter (for which prognostic estimations are needed to do actions) the ranges of acceptable conditions can be established. The traced conditions of monitored parameters are data about a condition before and on the current moment of time. For example, the ranges of possible values of conditions may be established: “Working range inside of norm”, “Out of working range, but inside of norm”, “Abnormality” for each separate critical parameter. If the parameter ranges of acceptable conditions are not established in explicit form then for modeling purpose the may be implead and can be expressed in the form of average time value. These time values are used as input for probabilistic modeling. For example, for coal mine some of many dozens heterogeneous parameters are: for ventilation equipment - temperature of rotor and engine bearings, a current on phases and voltage of stator; for modular decontamination equipment - vacuum in the pipeline, the expense and temperature of a metano-air mix in the pipeline before equipment, pressure in system of compressed air, etc. It may be interpreted similarly by light signals – “green”, “yellow”, “red” - see Figure 8 and following Example 6.3.

4. Optimization Problem Statements for Rationale Actions

The proposed optimization problem statements for rationale actions helps to implement idea 7. For example the proposed ideas 2-6 may be supported by the next typical optimization problem statements for AIS [25,28,30]:

(1) on the stages of system concept, development, production and support: system parameters, software, technical and control measures ($Q$) are the most rational for the given prognostic period if on them the minimum of expenses ($Z_{dev.}$) for creation is reached

$$Z_{dev.}(Q_{rational}) = \min Q_{z_{dev.}}(Q),$$

(1A) at limitations on probability of an admissible level of quality $P_{quality}(Q) \geq P_{adm}$ and expenses for operation $C_{oper}(Q) \leq C_{adm}$ and under other development, operation or maintenance conditions; or

(1B) at limitations on admissible risk to lose system integrity $R_{R_{adm}}$ and expenses for operation $C_{oper}(Q) \leq C_{adm}$ and under other development, operation or mainte-

Figure 7. An example of complex system integrating two serial complex intellectual structures which also are complex subsystems (abstraction)

Figure 8. An example of universal elementary ranges for monitoring data about events and conditions

Figure 8. An example of universal elementary ranges for monitoring data about events and conditions

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nance conditions; or
(1C) at limitations presented as combination 1A) and 1B);
(2) on utilization stage:
(A) system parameters, software, technical and control measures (Q) are the most rational for the given period of AIS operation if on them the maximum probability of correct system operation is reached
\[ P_{\text{quality}}(Q_{\text{rational}}) = \max P_{\text{quality}}(Q), \]

(2A.a) at limitations on probability of an admissible level of quality \( P_{\text{quality}}(Q) \geq P_{\text{adm}} \) and expenses for operation \( C_{\text{oper}}(Q) \leq C_{\text{adm}} \) and under other operation or maintenance conditions; or
(2B.a) at limitations on admissible risk to lose system integrity \( R \leq R_{\text{adm}} \) and expenses for operation \( C_{\text{oper}}(Q) \leq C_{\text{adm}} \) and under other operation or maintenance conditions; or
(2A.c). at limitations presented as combination 2A.a) and 2A.b);
(B) system parameters, software, technical and control measures (Q) are the most rational for the given period of system operation if on them the minimum of risk to lose system integrity is reached
\[ R(Q_{\text{rational}}) = \min R(Q), \]

(2B.a) at limitations on probability of an admissible level of quality \( P_{\text{quality}}(Q) \geq P_{\text{adm}} \) and expenses for operation \( C_{\text{oper}}(Q) \leq C_{\text{adm}} \) and under other operation or maintenance conditions; or
(2B.b) at limitations on admissible risk to lose system integrity \( R \leq R_{\text{adm}} \) and expenses for operation \( C_{\text{oper}}(Q) \leq C_{\text{adm}} \) and under other operation or maintenance conditions; or
(2B.c). at limitations presented as combination 2A.a) and 2A.b);

These statements may be transformed into the problems of expenses minimization in different limitations. There may be combination of these formal statements in system life cycle.

Note. Another variants of optimization problem statements are possible.

5. The incremental algorithms for solving the problems 1 and 2

The proposed algorithms for solving the problems 1 and 2 are based on using the models and methods above.

5.1 The Algorithm for Solving Problem to Rationale a Rational Variant for Decision-making on the Base of Monitored Data About Events and Conditions (problem 1)

It is supposed that the terms “success” and accordingly “unsuccess” (“failure”) are defined in terms of admissible condition of interested system to operate for the purpose according to required quality.

Note: For example for each parameter of equipment the ranges of possible values of conditions may be estimated as “Working range inside of norm” and “Out of working range, but inside of norm” (“success”) or “Abnormality” (“failure”), interpreted similarly light signals – “green”, “yellow”, “red”. For this definition a “failure” of equipment operation characterizes a threat to lose system norm integrity after danger influence (on the logic level this range “Abnormality” may be interpreted analytically as failure, fault, losses of quality or safety etc.).

The proposed steps for solving problem 1 to rationale a rational variant for decision-making on the base of monitored data about events and conditions may be carried out by the next 4 steps – see Figure 9.

---

Figure 9. Steps for solving problem 1

**Step 1.** The complete set of variants for actions is defined, including for each variant – a definition of compound components is being. Each use case may be characterized by an expected benefit in comparable conventional units. If the objective value of a benefit can’t be defined, expert value of a level of “success” may be established, for example, on a dimensionless scale from 0 to 100 (0 – “no benefit”, i.e. “failure”, 100 – “the maximal benefit”, i.e. complete “success”).

**Step 2.** The measures and optimization criteria are chosen (see sections 3 and 4). As criteria there can be accepted:

1. maximum of benefit as a result of system operation under the given conditions and limitations on the acceptable risk of “failure” and/or other limitations;
2. maximum probability of “success” or minimum risk of “failure” under limitations.

**Step 3.** The knowledge is used to refine the input for modeling. Using the probabilistic models and methods for each variant, the “success” measures are calculated for the given prognostic period. From a set of possible variants the optimal one is chosen according to the step 2 criterion.
**Note:** Formal statements of optimization may be connected with maximization of benefit at limitations on admissible levels of quality and/or risks measures or with minimization of risks at limitations on admissible levels of benefit and/or quality and/or risks measures and/or under other operation or maintenance conditions (see section 4).

**Step 4.** A decision for the optimal variant of actions (defined in step 3) is made. In support of the efficiency of the functions, the achievable benefit calculated at step 3 is recorded. New knowledge is improved and systematized by comparing it with reality (including comparisons of probabilistic estimations and real events).

**Note:** A solution that meets all conditions may not exist. In this case, there is no optimal variant of system operation on the base of monitored data about events and conditions.

### 5.2 The Algorithm for Solving Problem to Rationale a Robot Actions under Limitations on Admissible Risks of “Failures” (problem 2)

The approach for solving problem 2 to rationale a robot actions under limitations of admissible risks of “failures” is demonstrated in application to robot route optimization in conditions of uncertainties.

For a robot, the concept of “failure” under uncertainty is defined as the failure to achieve the goal within a given time. It is assumed that there are several possible routes to achieve the goal, and uncertainties may include both the conditions for robot operation (including random events in orientation, localization and mapping). The minimum risk of “failure” under the existing conditions and limitations is set as a criterion of optimization.

The proposed steps for solving problem 2 of robot route optimization under limitations on admissible risks of “failure” under conditions of uncertainties may be carried out by the next 4 steps – see Figure 10.

**Figure 10.** Steps for cognitive solving problem 2

**Step 1.** The complete set of route variants to achieve the goal within the given time, and for each variant – a set of components, is defined (redefined). Data characterizing every part of route for each of the variants are gathered (refined) for modeling. To do this, a specific robot can use data from various sources (for example, from air drones, intelligent buoys on the water or sensors under water, etc.). If necessary, possible damages are taken into account. For example, each use case may be characterized by an expected damages in comparable conventional units. If the objective value of a damage can’t be defined, expert value of expected level of “failure” for each variant may be set, for example, on a dimensionless scale from 0 to 100 (0 – “no damages”, i.e. “success”, 100 – “the maximal damage”).

The index i of the first part of the selected route is set to the initial value i=1.

**Step 2.** The knowledge is used to refine the input for prognostic modeling. Using probabilistic model, a calculation of the probability of “failure” (risk of “failure”) is carried out for each variant. From the set of variants (remaining route) the optimal one is chosen, for its the minimum probability of “failure” (risk of “failure”) is achieved.

**Step 3.** The robot overcomes the i-th part of the selected route. If the part can’t be overcome, the comeback to the initial point of the part is being. If an alternative route isn’t here, the comeback to initial point of the previous part is being. The input for modeling every part of possible route for each of the variants are updated. New knowledge is improved and systematized by comparing it with reality (including comparisons of prognostic risks and real events).

**Step 4.** If, after overcoming the i-th part, the robot arrived at the intended point of route (i.e., the last part of the route is overcome and the goal is achieved), then the solution for optimizing the route is complete. If the robot hasn’t yet arrived at the intended point (i.e. the last part of the route isn’t overcome), then the complete set of different route variants for achieving the goal is redefined (similar to step 1). The input for modeling every part of possible route for each of the variants are updated, i= i+1. Then steps 2-4 are repeated until the last part of the route is overcome on the set of possible variants (i.e. it means the goal is achieved and problem 2 is solved).

If the set of possible options is exhausted and the goal is not achieved, it is concluded that the goal is unattainable with the risk of “failure” less than the acceptable risk (i.e., it means an impossibility of solving problem 2 in the defined conditions).

Thus, to rationale a robot actions under limitations on admissible risks of “failures” (i.e. to a “successful” solution of problem 2) in real time, information gathering, probabilistic predictions for possible route variants, their comparison, the choice of the best variant, the implementation of further actions, the improvement, systematization
and use of knowledge are being.

6. Examples

6.1 About a Period of Successful System Operation by AIS Capabilities

The example is related partly to solving the problem 1 and concerning an estimation of successful system operation during a long time by AIS capabilities in comparison against an usual system without or with usual sensors (without artificial intelligence capabilities to logic reasoning).

How long time may be a period of successful system operation by AIS capabilities? And what about conditions for this long period?

Those threats to system operation which are known, traced at diagnostics and do not cause irreversible consequences at the first influence, are considered only. Besides, it is supposed, that an integrity can be operatively recovered after AIS recovering reaction at the earliest stages of detection of dangerous or guarding symptoms. Moreover, at modeling the time of full integrity recovering is artificially reduced till diagnostic time. Thus, the elementary condition “acceptable integrity” means such system state when system purposes are achieved with the required quality, i.e. absence of danger source or neutralization of a penetrated source at the earliest stage prior to its danger influence after activation. It (as supposed by the model) enough for successful AIS operation.

Note: The above assumptions are supposed for modeling. In a reality it may be not always so. These conditions are considered for interpretation of modeling results.

To compare system operation with AIS capabilities against an usual system (without artificial intelligence capabilities) for the same conditions we consider AIS possibilities to provide “acceptable integrity” by continuous monitoring with artificial intelligence logic reasoning. Let’s the threats to system integrity are being about 1 time a day because of natural or technogenic threats and “human factor”. Let’s also after occurrence of a danger source an average activation time is equal to 6 hours, during which else it is possible to prevent or neutralize negative influence.

Two variants of reaction caring of AIS integrity are compared. 1st variant (an usual system) considers the address to a recovering center about 1 time a month and reception of necessary recovering procedures within 4 hours after diagnostics. 2nd variant means AIS performing functions of diagnostics every 4 hours and recovering acceptable integrity within one hour. For all variants mean time between operator’s error during continuous monitoring of system integrity is estimated not less than 1 year (for general technology 2). Initial input data for probabilistic modeling are reflected by the Table 1, the used model is described in subsection 3.2 of this paper.

<table>
<thead>
<tr>
<th>Table 1. Input for estimation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Input for modeling</strong></td>
</tr>
<tr>
<td><strong>1-st (an usual system)</strong></td>
</tr>
<tr>
<td>The given prognostic period (“in future”)</td>
</tr>
<tr>
<td>The frequency of influences for penetrating into system</td>
</tr>
<tr>
<td>The mean activation time</td>
</tr>
<tr>
<td>The time between the end of diagnostic and the beginning of the next diagnostic</td>
</tr>
<tr>
<td>The diagnostic time</td>
</tr>
<tr>
<td>The mean time between operator’s error during continuous monitoring of system integrity</td>
</tr>
</tbody>
</table>

Some probabilities of providing system integrity in dependence on input, changing in diapason -50%+100% from Table 1 data, are presented on Figures 11-139. They cover dependences on the given prognostic period, the time between the end of diagnostic and the beginning of the next diagnostic, the mean time between operator’s error during continuous monitoring of integrity. Deviations for other dependences are insignificant.

Figure 11. The probability of providing system integrity in dependence on the given prognostic period

Figure 12. The probability of providing system integrity in dependence on the time between the end of diagnostics and the beginning of the next diagnostics
The probability of providing system integrity in dependence on the mean time between operator’s errors during continuous monitoring of system integrity

Results of modeling show, that for 1\textsuperscript{st} variant (for an usual system) the probability to provide “acceptable integrity” during 1 year is equal to 0.39, during 2 years – not less than 0.16, during 3 years – only 0.07. It means practically the inevitability of a failure during 2-3 years. 2\textsuperscript{nd} variant (for AIS) with operative recovering is more effective. Really, it is possible to provide “acceptable integrity” for system operation with AIS capabilities within 3-5 years with probability about 0.90-0.93 – it may be interpreted as successful operation 9 times from 10 possible five-year periods. These results of modelling should serve a rationale for development counteractions against threats.

Conditions for five-year period of successful system operation with AIS capabilities are presented in Table 1 for 2\textsuperscript{nd} variant.

Note. Serrated and nonmonotonic character of dependence on Figures 11, 12 (left) is explained by the periodic diagnostics, monitoring presence or absence and their quantitative values, and also because of parameter “N” is integer part – see Appendix B. Details see in \cite{30}.

Of course the concepts “acceptable integrity” and “failure” of special system should be defined in details (which produced input for modeling). However the expected modeling results against typical plausible input for this this simple example has also demonstrated for readers a suitability of the proposed probabilistic “Black box” models (from section 3).

6.2 Example 2 of Acceptable Requirements to Solve Problem 1 for Information Systems Operation

The example is connected with rationale a rational requirements to information system (IS) operation for providing high information quality for using in an AIS. Information systems are systems for which input is information and output (as result of IS operation) also is information for following use according to purpose. This example summarizes the numerous results of researches performed for IS operating in government agencies, manufacturing structures (including power generation, coal enterprises, oil-and-gas systems), emergency services etc. \cite{20,25,28,30-33,35-45}. The results are based on described modeling to provide quality of output information producing, quality of used information IS and security of IS operation (see Table A.1 from Appendix A).

According to this generalization for the best practice of IS operation the acceptable requirements are the next (see the measures from Table 1):

1. to provide quality of output information producing:
   A. Probability of providing reliable function performance during given time should be no less than 0.99;
   B. System availability should be no less than 0.9995;
   C. Probability of well-timed calls processing during the required term should be no less than 0.95;
   D. Relative portion of well-timed processed calls of those types for which the customer requirements are met should be no less than 95%.

2. to provide quality of used information:
   A. Probability that system contains information about states of all real object and coincides should be no less than 0.9;
   B. Probability of information actuality on the moment of its use should be no less than 0.97;
   C. Probability of errors absence after checking should be no less than 0.97;
   D. Probability of correct analysis results obtaining should be no less than 0.95;
   E. Probability of providing information confidentiality during objective period should be no less than 0.999.

3. to provide security of IS operation:
   A. Probability of faultless (correct) operation under dangerous influence on IS during given time should be no less than 0.95;
   B. Probability of system protection against unauthorized access should be no less than 0.99.

These values characterizes some admissible limitations for probabilities of “success” (P) and risks of “unsuccess” (R=1-P) for information systems operation quality.

The fulfillment of these requirements is a certain scientifically proved guarantee of the quality of information used by AIS.

6.3 Example of Solving Inverse Problem to Estimate the Mean Residual Time before the Next Parameters Abnormalities for a Coal Company

The example demonstrates an AIS possibility on the base of solving inverse problem by model described in subsection 3.2 and Appendix B to a rationale of actions in a real time for a coal company.

Conditions of parameters, traced by dispatcher intelligence center, are data about a condition before and on the DOI: https://doi.org/10.30564/aia.v1i2.1195
current moment of time, but always the future is more important for all. With use of current data responsible staff (mechanics, technologists, engineers, etc.) should know about admissible time for work performance to maintain system operation. Otherwise because of ignorance of a residual time resource before abnormality the necessary works are not carried out. I.e. because of ignorance of this residual time it is not undertaken measures for prevention of negative events after parameters abnormalities (failures, accidents, damages and-or the missed benefit because of equipment time out). And on the contrary, knowing residual time before abnormality these events may be avoided, or system may be maintained accordingly. For monitored critical system the probabilistic approach to estimate the mean residual time before the next parameters abnormalities for each element and whole system is proposed.

For every valuable subsystem (element) monitored parameters are chosen, and for each parameter the ranges of possible values of conditions are established: “In working limits”, “Out of working range, but inside of norm”), “Abnormality” (interpreted similarly light signals – “green”, “yellow”, “red”) – see Figures 8 and 14. The condition “Abnormality” characterizes a threat to lose system integrity.

For avoiding the possible crossing a border of “Abnormality” a prediction of residual time, which is available concerning of unknown parameter t, i.e. Tresid = t0.

Here R(Tpenetr, t, Tbetw, Tdiag, Treq.) is risk to lose integrity, it is addition to 1 for probability P(Treq) of providing system integrity (“probability of success”), for calculations the formulas (B.1)–(B.3). Tpenetr is the mathematical expectation of PDF Ωpenetr (t), it is defined by parameter statistics of transition from “green” into “yellow” range (see Figure 8). The others parameters Tbetw, Tdiag in (3) are known – see Appendix B. The main practical questions are: what about Treq and what about a given admissible risk Radm(Treq)? For answering we can use the properties of function R(Tpenetr, t, Tbetw, Tdiag, Treq.):

1) if parameter t increases from 0 to ∞ for the same another parameters, the function R(…, t, …) is monotonously decreasing from 1 to 0 (for N – real, i.e. no integer part), if the mean activation time of occurred danger (threat - from the 1-st input at the “yellow” range to the 1-st input in the “red” range) is bigger to lose integrity is less;

2) if parameter Treq increases from 0 to ∞ for the same another parameters, the function R(…,Treq) is monotonously increasing from 0 to 1, i.e. for large Treq risk approaches to 1.

It means the such maximal x exists when t=x and Treq=x and 0<R(Tpenetr, x, Tbetw, Tdiag, x)<1. I.e. the residual time before the next parameter abnormality (i.e. time before first next coming into “red” range) is equal to defined x with confidence level of admissible risk R(Tpenetr, x, Tbetw, Tdiag, x). So, if Tpenetr =100 days, for Radm = 0.01 residual time x≈2.96 weeks (considering decisions of recovery problems of integrity every 8 hours). Adequate reaction of responsible staff in real time is transparent for all interested parties. Details see [35].

6.4 Example of Solving Problem 1 by AIS Operating for Providing Safety of a Floating Oil and Gas Platform

For estimation and rationale the possibilities of a floating oil and gas platform operation (considered as a system) the probabilistic modeling is being to answer the next question: “What risks to lose system integrity may be for a year, 10 and 20 years if some subsystems are supported by special AIS on the levels which are proper to skilled workers (optimistic view) and to medium-level workers (realistic view)?”

Let for studying efficiency a system is decomposed on 9 subsystems, for example - see Figure 15. System components are: 1st - a construction of platform; 2nd - an AIS on platform for robotics monitoring and control; 3rd - an underwater communication modem; 4th - a remote controlled unmanned underwater robotic vehicle; 5th - a sonar beacon; 6th - an autonomous unmanned underwater robotic vehicle; 7th - non-boarding robotic boat - a spray of
the sorbent; 8th - non-boarding robotic boat – a pollution collector; 9th - an unmanned aerial vehicle. Data is monitored from different sources and processed by the models described above in section 3.

**Note:** Of course every subsystem also may be considered as a special complex system.

The information from monitored data and a time data of enterprises procedures are used as input for using models from Table A.2 and performing steps 1-4 (from Figure 9) in real time. Here risks to lose system integrity during given period $T_{\text{given}}$ means risks to be at least once in state “Abnormality” within $T_{\text{req}}$. The functions of modeling may be performed on special servers (centralized or mapped). If virtual risks are computed for all points $T_{\text{req}}$ from 0 to $\infty$, the calculated values form a trajectory of the PDF. The mathematical expectation of this PDF means the mean residual time to the next state “Abnormality”. It defines mean time before failures (MTBF) from this PDF.

Requirements to IS operation quality should meet admissible levels recommended in Example 2.

To answer the question of the example let the next input are formed from data monitored and the time data of enterprises procedures.

Let for every system component a frequency of occurrence of the latent or obvious threats is equal to once a month, mean activation time of threats is about 1 day. The system diagnostics are used once for work shift 8 hours, a mean duration of the system control is about 10 minutes, mean recovery time of the lost integrity of object equals to 1 day. The workers (they may be robotics, skilled mechanics, technologists, engineers etc.) are supported by capabilities of an intellectual system allowing estimations in real time the mean residual time before the next parameters abnormalities. Formally they operate as parallel elements with hot reservation. Workers are capable to revealing signs of a critical situation after their occurrence owing to the support of intellectual systems. If all subsystems are supported by intellectual systems on the level which is proper to skilled workers (optimistic view), workers can commit errors on the average not more often once a year. If all subsystems are supported by intellectual system on the level which is proper to medium-level workers (realistic view) only one difference is – medium-level workers can commit errors more often in comparison with skilled workers, for one element it is equal to 1 time a month instead of once a year.

Further we do the steps 1-4 from Figure 9. Computed risks to lose system integrity on Figure 15 means the risks of “failure” for every subsystem which can be detailed to the level of every separate critical parameter of equipment.

The fragments of built PDFs on Figure 15 show:

1) if all subsystems are supported by intellectual system on the level which is proper to skilled workers (optimistic view) the risk of “failure” increases from 0.000003 for a year to 0.0004 for 10 years and to 0.0013 for 20 years. The MTBF equals to 283 years;  
2) if all subsystems are supported by intellectual system on the level which is proper to medium-level workers (realistic view) the risk of “failure” increases from 0.0009 for a year to 0.0844 for 10 years and 0.25 for 20 years. The MTBF equals to 24 years. It is 11.4 times less against the results for optimistic view.

Such effects (MTBF = 283 years for optimistic view and MTBF = 24 years for realistic view) are owing to implemented technology of counteractions to threats. These are some estimations for example assumptions. Please, compare the effects against primary frequency of occurrence of the latent or obvious threats is equal to once a month, mean activation time of threats is about 1 day + workers errors.

**6.5 Example of Solving Problem 2 for a Robot Route Optimization**

Applicability of the proposed probabilistic methods and models to solving problem 2 (of robot actions optimization under limitations on admissible risks of “failure”) is
demonstrated to improve some of the existing capabilities of a rescue robot, interconnected with accessory drone, for route optimization in conditions of uncertainties. Similar problems of specific rescue robot route optimization from point A (Start) to point E (End) can arise in burning wood, in mountains, in the conditions of a city, and in other situations in conditions of uncertainties. Specific cases of uncertainties can be connected additionally with complex conditions of environment and necessity of robotics orientation, localization and mapping that influences on input for the proposed probabilistic models.

On this simplified hypothetical example of moving some rented values by means of the pilotless car from point A to the final point E of a route (from where the SOS signals are following) we will demonstrate the proposed approach to route optimization with acceptable risk of “failure” less than 0.1 (i.e. a probability of success should be more than 0.9) under conditions of uncertainties during the route – see Figure 16.

![Image of robot route](Figure 16. Possible robot route from point A (Start) to point E (End))

The next steps from Figure 10 are performed.

**Step 1.** The complete set of route variants to achieve the goal within given 2 hours, and for each variant – a set of components, is defined: ABCDE, ABGKLDE, ABGHLDE. Let data characterizing every part of route for each of the variants are gathered from drone-informant, processed and prepared for modeling - frequencies of the occurrences of potential threats are: for ABCDEF = 1 time at 10 hours, ABGKLDEF = 1.5 times at 10 hours, ABGHLDE = 2 times at 10 hours (since 08.00 a.m. to 18.00 a.m. what is connected with drone capabilities); mean activation time of threats = 30 minutes; time between the end of diagnostics and the beginning of the next diagnostics = 2 minutes; diagnostics time = 30 seconds; recovery time = 10 minutes; given prognostic period =2 hours. 

\[ i=1 \]

**Step 2 (i=1).** Using probabilistic model, a calculation of the probability of “failure” is carried out for each variant. From the set of variants ABCDE, ABGKLDE, ABGHLDE the shorter variant ABCDE for which risk is equal to 0.034 is chosen (for the route ABGKLDEF risk=0.051, for route ABGHLDEF risk=0.067). The relevant data from the drone about the local fire conditions and the weather on the part BCDE to 8.00 a.m. are taken into account.

**Step 3 (i=1).** The robot overcomes the part AB of route. For the new initial point B the input for modeling every part of possible route are updated in real time for routes BCDE, BGKLDE, BGHLDE.

**Step 4 (i=1).** The robot hasn’t yet arrived at the intended point E (i.e. the last part of the route isn’t overcome). 

\[ i=i+1=2 \]

**Step 2 (i=2 for variants BCDE, BGKLDE, BGHLDE).** Input for modeling isn’t changed. Risks are the same. From the route variants BCDE, BGKLDE, BGHLDE the shorter one BCDEF (with minimal risk) is chosen.

**Step 3 (i=2 for variant BCDE).** The robot overcomes the part BC. For the new initial point C the input for modeling every part of possible route are updated in real time: dense fog in forest thicket on the CD part does not allow further movement. And additional information for robot is: the local weather improvements in the next 2 hours are not expected. Part CD is impassable. The comeback to the initial point B of the part is being.

**Step 2 (i=2 for two remaining variants).** From variants BGKLDE, BGHLDE the shorter one BGKLDE (with minimal risk 0.051) is chosen.

**Step 3 (i=2 for variant BGKLDE).** The robot overcomes the part BG. For the new initial point G the input for modeling every part of possible route are updated in real time: according drone from 9.00 a.m. on parts GK and KL the imminent fire is detected. The gathered information and knowledge are used to clarify the input for modeling, namely: the frequency threats in the part GKL increases from 1.5 to 2.5 times at 10 hours. Using a probabilistic model for each variant, a recalculation of the risk of failure is carried out. Of the variants GKLDE, GHLDE the variant GHLDE is chosen (risk is equal to 0.067, for the route GKLDE risk equals 0.083).

**Step 4.** After overcoming the part GHLDE the robot arrived at the intended point E of route in given time. Thus the way ABCBGLHDE is the result of optimization before and on the route. The robot purpose was achieved owing to preventive measures which were de-
fined by using risk control on the way (with controlled probability of “success” more than 0.9).

6.6 What about the Possible Pragmatic Effects from Probabilistic Rationale of Actions for AIS?

Author of this article took part in creation of the Complex of supporting technogenic safety on the systems of oil&gas transportation and distribution and have been awarded for it by the Award of the Government of the Russian Federation in the field of a science and technologies. The AIS is a part of the created peripheral posts are equipped additionally by means of Complex to feel vibration, a fire, the flooding, unauthorized access, hurricane, and also intellectual means of the reaction, capable to recognize, identify and predict a development of extreme situations – see engineering decisions on Figure 17.

The proposed models include models to estimate AIS operation quality and risks prediction for system formalized as “Black box”, algorithm to build new probabilistic models for complex system. The practical way to data forming for probabilistic modeling is described.

A suitability of the approach is demonstrated by examples about:

(1) a period of successful system operation by AIS capabilities;
(2) acceptable requirements to solve problem 1 for information systems operation;
(3) solving inverse problem to estimate the mean residual time before the next parameters abnormalities for a coal company;
(4) solving problem 1 by AIS operating for providing safety of a floating oil and gas platform;
(5) solving problem 2 for a robot route optimization;
(6) the possible pragmatic effects from probabilistic rationale of actions for AIS.

The proposed approach means practically a proactive commitment to excellence in uncertainty conditions.

Appendix A. The Models to Estimate AIS Operation Quality

The probabilistic models for the estimation of information systems operation quality are presented by the formulas (A.1) – (A.14) in Table A.1.

Table A.1 The probabilistic models for the estimation of information systems operation quality (the proof and details - see [20-22,24,25,28])

<table>
<thead>
<tr>
<th>Models. Input</th>
<th>Evaluated measures</th>
</tr>
</thead>
<tbody>
<tr>
<td>The model of functions performance by a complex system in conditions of unreliability of its components. Input: N(t) - is the probability distribution function (PDF) of time between neighboring failures ((T_{MTBF_{nk}}) is the mean time); W(t) – is the PDF of repair time ((T_{rep.}) is the mean time); V(t) – is the PDF of given time if this time is random value ((T_{req.}) is the mean time).</td>
<td>Probability (P_{rel}) of providing reliable function performance during given time. (P_{rel} = \int \left[ V(t) - (t) \right] dt = \int \left[ N(t) \ast W(t) \right] dt )</td>
</tr>
<tr>
<td>Note. The next variants are used by the software tools [35-37]. N(t), W(t) are exponentially distributed (i.e. enough mean times - (T_{MTBF_{nk}}, T_{rep.})), V(t) is determined (i.e. (T_{req.}) is const).</td>
<td></td>
</tr>
</tbody>
</table>

DOI: https://doi.org/10.30564/aia.v1i2.1195
The models complex of calls processing for the different dispatcher technologies.  

**Input**: for $G/1/c_2$

- $\lambda_i$ – frequency of the $i$-th type calls for processing;
- $\beta$ – mean processing time of the $i$-th type calls (without queue).

Note. The software tools allow to estimate and to compare effectiveness of the next dispatcher technologies for modeling by $G/M/G/1/c_2$:
- $\beta$ - for apriority calls processing: in a consecutive order for single-tasking processing mode;
- $\beta$ - for multitasking processing mode;
- $\beta$ - for multi-sharing order for dispatching processing (with relative priorities and in the order FIFO) inside a batch) ($\beta$) technology 5 is a combination of technologies 2, 3, 4 ($\beta$).

### Models. Input

<table>
<thead>
<tr>
<th>Models. Input</th>
<th>Evaluated measures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Probability $P_{\text{tim}}$, false of well-timed processing of $i$-type calls during the required term $P_{\text{tim}} = \frac{1}{1 - \Phi(B(t))} = \frac{1}{1 - \Phi(\beta(t))}$ (A.3).</td>
<td>The model of information gathering.</td>
</tr>
<tr>
<td>$\Phi(x) = \sum_{n=0}^{\infty} \frac{x^n}{n!}$ is productive (generating) function; $B(t)$ is the PDF of time for new information revealing and preparing, transfer and entering into data base. Note. The next variants are used by the software tools (A.4).</td>
<td>Input: $C(t)$ is the PDF of time between essential changes of object states, $\xi_i$ – is the mean time; $B(t)$ is the PDF of time for information gathering and preparing, transfer and entering into system; $Q(t)$ is the PDF of time interval between information updating, $q$ is the mean time (only for mode $D_1$); the mode of $D_2$, gathering: information is gathered in order “immediately after an essential object state change; the mode $D_3$: gathering: information is gathered without any dependencies on changes of object current states (including regulated information gathering). Note. The next variants are used by the software tools (A.5).</td>
</tr>
</tbody>
</table>

### Models. Input

<table>
<thead>
<tr>
<th>Evaluated measures</th>
<th>Probability $P_{\text{act}}$, of information actuality on the moment of its use:</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1) for the mode $D_1$, when information is gathered in order “immediately after an essential object state change: $P_{\text{act}} = \frac{1}{1 - C(t)}B(t){1 - C(t)}dt$, (A.4).</td>
<td>(2) for the mode $D_2$, when information is gathered without any dependencies on changes of objects current states (including regulated information gathering) $P_{\text{act}} = \frac{1}{1 - C(t)}C(t){1 - C(t)}dt$, (A.5).</td>
</tr>
</tbody>
</table>

The model of entering into system current data concerning new objects of application domain.  

**Input:** $q_{\text{nl}}$ - the probability that m new objects appear in random moment, intervals between these moments are exponentially distributed with parameter $\lambda$, $\Phi(x) = \sum_{n=0}^{\infty} x^n/n!$ - is productive (generating) function; $B(t)$ is the PDF of time for new information revealing and preparing, transfer and entering into data base. Note. The next variants are used by the software tools (A.6). |

| Probability $\Phi(x)$ that system contains information about states of all real object and coincides $\Phi(x) = \sum_{n=0}^{\infty} x^n/n!$ is productive (generating) function; $B(t)$ is the PDF of time for new information revealing and preparing, transfer and entering into data base. Note. The next variants are used by the software tools (A.6). | The model of information analysis. |
| $\Phi(x) = \sum_{n=0}^{\infty} x^n/n!$ - is productive (generating) function; $B(t)$ is the PDF of time for new information revealing and preparing, transfer and entering into data base. Note. The next variants are used by the software tools (A.6). | Input: $\tau_m$ - assigned term for analysis; $N(t)$ is the PDF of time between essential changes of object states; $\xi_i$ – is the mean time; $\mu$ is the mean time; $B(t)$ is the PDF of time for information gathering and preparing, transfer and entering into system; $Q(t)$ is the PDF of time interval between information updating, $q$ is the mean time (only for mode $D_1$); the mode of $D_2$, gathering: information is gathered in order “immediately after an essential object state change; the mode $D_3$: gathering: information is gathered without any dependencies on changes of object current states (including regulated information gathering). Note. The next variants are used by the software tools (A.5). |

### Probability of errors after checking (probability $P_{\text{act}}$ of correct analysis results obtaining):  

**Variant 1.** An assigned term for analysis is no less than the real analysis time (i.e. $T_{\text{req}} \leq T_{\text{cont}}$).  

| $T_{\text{req}}$ - assigned term for analysis; $N(t)$ is the PDF of time between essential changes of object states; $\xi_i$ – is the mean time; $\mu$ is the mean time; $B(t)$ is the PDF of time for information gathering and preparing, transfer and entering into system; $Q(t)$ is the PDF of time interval between information updating, $q$ is the mean time (only for mode $D_1$); the mode of $D_2$, gathering: information is gathered in order “immediately after an essential object state change; the mode $D_3$: gathering: information is gathered without any dependencies on changes of object current states (including regulated information gathering). Note. The next variants are used by the software tools (A.5). | The model of information analysis. |
| $\Phi(x) = \sum_{n=0}^{\infty} x^n/n!$ - is productive (generating) function; $B(t)$ is the PDF of time for new information revealing and preparing, transfer and entering into data base. Note. The next variants are used by the software tools (A.6). | Input: $\tau_m$ - assigned term for analysis; $N(t)$ is the PDF of time between essential changes of object states; $\xi_i$ – is the mean time; $\mu$ is the mean time; $B(t)$ is the PDF of time for information gathering and preparing, transfer and entering into system; $Q(t)$ is the PDF of time interval between information updating, $q$ is the mean time (only for mode $D_1$); the mode of $D_2$, gathering: information is gathered in order “immediately after an essential object state change; the mode $D_3$: gathering: information is gathered without any dependencies on changes of object current states (including regulated information gathering). Note. The next variants are used by the software tools (A.5). |

### Probability of errors after checking (probability $P_{\text{act}}$ of correct analysis results obtaining):  

**Variant 2.** An assigned term for analysis is no less than the real analysis time (i.e. $T_{\text{req}} \leq T_{\text{cont}}$).  

| $T_{\text{req}}$ - assigned term for analysis; $N(t)$ is the PDF of time between essential changes of object states; $\xi_i$ – is the mean time; $\mu$ is the mean time; $B(t)$ is the PDF of time for information gathering and preparing, transfer and entering into system; $Q(t)$ is the PDF of time interval between information updating, $q$ is the mean time (only for mode $D_1$); the mode of $D_2$, gathering: information is gathered in order “immediately after an essential object state change; the mode $D_3$: gathering: information is gathered without any dependencies on changes of object current states (including regulated information gathering). Note. The next variants are used by the software tools (A.5). | The model of information analysis. |
| $\Phi(x) = \sum_{n=0}^{\infty} x^n/n!$ - is productive (generating) function; $B(t)$ is the PDF of time for new information revealing and preparing, transfer and entering into data base. Note. The next variants are used by the software tools (A.6). | Input: $\tau_m$ - assigned term for analysis; $N(t)$ is the PDF of time between essential changes of object states; $\xi_i$ – is the mean time; $\mu$ is the mean time; $B(t)$ is the PDF of time for information gathering and preparing, transfer and entering into system; $Q(t)$ is the PDF of time interval between information updating, $q$ is the mean time (only for mode $D_1$); the mode of $D_2$, gathering: information is gathered in order “immediately after an essential object state change; the mode $D_3$: gathering: information is gathered without any dependencies on changes of object current states (including regulated information gathering). Note. The next variants are used by the software tools (A.5). |

### Probability of errors after checking (probability $P_{\text{act}}$ of correct analysis results obtaining):  

**Variant 1.** An assigned term for analysis is no less than the real analysis time (i.e. $T_{\text{req}} \leq T_{\text{cont}}$).  

| $T_{\text{req}}$ - assigned term for analysis; $N(t)$ is the PDF of time between essential changes of object states; $\xi_i$ – is the mean time; $\mu$ is the mean time; $B(t)$ is the PDF of time for information gathering and preparing, transfer and entering into system; $Q(t)$ is the PDF of time interval between information updating, $q$ is the mean time (only for mode $D_1$); the mode of $D_2$, gathering: information is gathered in order “immediately after an essential object state change; the mode $D_3$: gathering: information is gathered without any dependencies on changes of object current states (including regulated information gathering). Note. The next variants are used by the software tools (A.5). | The model of information analysis. |
| $\Phi(x) = \sum_{n=0}^{\infty} x^n/n!$ - is productive (generating) function; $B(t)$ is the PDF of time for new information revealing and preparing, transfer and entering into data base. Note. The next variants are used by the software tools (A.6). | Input: $\tau_m$ - assigned term for analysis; $N(t)$ is the PDF of time between essential changes of object states; $\xi_i$ – is the mean time; $\mu$ is the mean time; $B(t)$ is the PDF of time for information gathering and preparing, transfer and entering into system; $Q(t)$ is the PDF of time interval between information updating, $q$ is the mean time (only for mode $D_1$); the mode of $D_2$, gathering: information is gathered in order “immediately after an essential object state change; the mode $D_3$: gathering: information is gathered without any dependencies on changes of object current states (including regulated information gathering). Note. The next variants are used by the software tools (A.5). |
The models complex of an authorized access to system resources during objective period.

Input (for estimation of confidentiality):
M is the conditional number of a barriers against an unauthorized access;
F_m(t) is the PDF of time between changes of the m-th barrier parameters;
U_m(t) is the PDF of parameters decoding time of the m-th security system barrier, u_m – the mean time of a barrier overcoming;
H(t) – is the PDF of objective period, when resources value is high.

Note. The next variants are used by the software tools [35-37]:
U_m(t) is exponentially distributed; F_m(t) and H(t) are determined or exponentially distributed.

The models complex of dangerous influences on a protected system.

Input:
Ω_mover(t) – is the PDF of time between neighboring influences for penetrating a danger source, for Ω_mover(t)=1-e^{-βt}, β – is the frequency of influences for penetrating;
Ω_mact(t) – is the PDF of activation time of a penetrated danger source, for Ω_mact(t)=1-e^{-βt}, β – is the mean activation time;
T_mact – is the required period of permanent secure system operation;
T_betw. – is the time between the end of diagnostic and the beginning of the next diagnostic, T_mdiag is the diagnostic period.

Note. The next variants are used by the software tools [35-37]:
Ω_mover(t) and U_m(t) are exponentially distributed.

The models complex of an authorized access to system resources.

Input (for estimation of confidentiality):
M is the conditional number of a barriers against an unauthorized access;
F_m(t) is the PDF of time between changes of the m-th barrier parameters;
U_m(t) is the PDF of parameters decoding time of the m-th security system barrier, u_m – the mean time of a barrier overcoming;
H(t) – is the PDF of objective period, when resources value is high.

Note: The final clear analytical formulas are received by Lebesque-integration of (A.1) – (A.6), (A.10), (A.14).

Table B.1 – The models to predict risks for “Black box” (the proof and details - see [24, 25, 28, 30, 44-45]).

Appendix B. The Models to Predict Risks for “Black box”

The proposed models allow to estimate preventive risks for being control in real time. The approach for modeling is based on algorithmic building new probabilistic models – see Table B.1.

The probabilistic models for the estimation of preventive risks for being control in real time is presented by the formulas (B.1) – (B.6) in Table B.1.

Table B.1

<table>
<thead>
<tr>
<th>Models, methods</th>
<th>Evaluated measures</th>
<th>Formulas</th>
</tr>
</thead>
</table>
| The model for technology 1 (“Black box”). Note. Technology 1 (without monitoring between diagnostics) is based on periodical diagnostics of system integrity, that are carried out to detect danger sources penetration into a system or consequences of negative influences. The lost integrity can be detect only as a result of diagnostics, after which system recovery is started. Dangerous influence on system is acted step-by-step: at first a danger source penetrates into a system and then after its activation begins to influence. System integrity can’t be lost before a penetrated danger source is activated. A danger is considered to be real after only danger source has influenced on a system. Input:
Ω_mover(t) is the PDF of time between neighboring influences for penetrating a danger source;
Ω_mact(t) – is the PDF of activation time of a penetrated danger source;
T_mact – is the integer part of(T_mover(T_mdiag)) – is the integer part.

| Risk to lose system integrity (R). Probability of providing system integrity (P) | R=1-P considering consequences. Variant 1 – the given prognostic period T_mdiag is less than established period between neighboring diagnostics
(T_mdiag<T_mover+T_mact);
P(1)(T_mdiag)=1-Ω_mover(T_mdiag).

| B.2) Where N[Ω_mover(T_mover+T_mact)] is the integer part, T_mdiag=T_mover+N(Ω_mover+T_mact); measure b) |

| (B.3), where the probability of success within the given time P(1)(T_mdiag) is defined by (B.1). |
The model for technology 2 (“Black box”). Note. Technology 2, unlike the previous one, implies that operators alternating each other trace system integrity between diagnostics (operator may be a man or special device or their combination). In case of detecting a danger source an operator recovers system integrity. The ways of integrity recovering are analogous to the ways of technology 1. Faultless operator’s actions provide a neutralization of technology 1. Fault-integrity recovering are if an operator makes an error but a dangerous penetration of a danger source is possible only if an operator makes an error but a dangerous influence occurs if the danger is activated before the next diagnostic. Otherwise the source will be detected and neutralized during the next diagnostic.

**Input:**
Additionally to Input for technology 1: A(t) - is the PDF of time from the last finish of diagnostic time up to the first operator error

**Formulas**

\[
R=1-P \text{ considering consequences.}
\]

Variant 1 - \(T_{req} \leq T_{betw} + T_{diag}\):

\[
P_{r1}(T_{req}) = N((T_{betw} + T_{diag})/T_{req}) P_{11}(T_{betw} + T_{diag}) P_{11}(T_{req},(B.6)),
\]

where N is the same and the probability of success within the given time \(P_{11}(T_{req})\) is defined by (B.4)

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ARTICLE

School Debit Transaction Using Fingerprint Recognition System

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ABSTRACT

This paper proposed a fingerprint based school debit transaction system using minutiae matching biometric technology. This biometric cashless transaction system intensely shortens the luncheon line traffic and labour force compared to conventional cash payment system. Furthermore, contrast with card cashless transaction system, fingerprint cashless transaction system with benefit that user need not carry additional identification object and remember lengthy password. The implementation of this cashless transaction system provides a more organize, reliable and efficient way to operate the school debit transaction system.

1. Introduction

Nowadays, parents need not to give cash directly to their primary/secondary schools' children. Some schools already practice to use their own debit card system, whereby students or their parents just need to bank in/ deposit the money to the school treasury department, the school treasury department will issue a debit card to students for purchasing food in canteen, stationaries, fees etc. This debit card system in favour by parents because they can monitor their children better due to the reason no cash for students to be get lost/stolen or purchasing outside drugs, tit-bit or unhealthy entertainment.

However, parents still have concerns, such as debit cards being stolen or misplaced by their children. There were a lot of wasteful resources for the system maintainer, as a new card had to be made for them who losing it. Besides that, students would also share their cards among friends, and sometimes the card can be scanned twice, lead to a double charged for a single transaction. Another concerning issue is if students forgot their identification number and PIN number of their card upon transaction, it might lead to a longer queuing time for other students, as primary and secondary students normally have 15-20 minutes’ break, the heavy traffic might lead to a waste of food and time. Therefore, a higher level of security and reliable system should be implemented to replace the conventional debit card transaction system, in order to create a convenient and safer environment for the children. Thus, biometric based debit transaction system is being proposed by researchers to overcome the above issues.[1,2]

Biometric authentication is a method of recognizing a human being according to the physiological measurements or physically features and traits [3]. The human physical characteristics such as fingerprints, face, hand geometry, voice and iris are known as biometrics. Biometric technologies are becoming the foundation of an

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extensive array of highly secure identification and personal verification solutions. Since biometric identifiers are associated permanently with the user, it is more reliable than the conventional authentication methods such as PIN and password. Thus, biometric based authentication can provide extra confidential in transactions by securing the personal information and privacy data.

In fact, there are many methods for biometric authentication. The most commonly used methods for biometric authentication are iris scanning [4], hand scanning [5], fingerprint recognition [6], face recognition [7], and voice recognition [8]. The biometric information will never ever match with another individual because everyone has their own unique biometric features. Researchers [9,10,11] had conducted numerous analysis and comparison among different types of biometric recognition methods. The comparison of biometric methods is mainly based on characteristics such as universality, uniqueness, performance, permanence, and measurability.

Based on the researchers’ results [9,10,11], fingerprint recognition has the highest market share among the technologies of biometric security system in the market. The preference of fingerprint recognition in the current market is mostly due to its high accuracy, performance and stability. Besides that, fingerprint recognition has a moderate pricing compare to iris scan which required a high capital cost and level of skills to operate and maintain. Moreover, it also has a relatively low percentage of False Acceptance Rate (FAR) and False Reject Rate (FRR) [12] which make it more reliable to use either in police or industrial area. Thus, fingerprint biometric recognition is widely acceptable and preferable compare to the other biometric security systems.

In this paper, a fingerprint recognition system will be proposed for replacing the debit card in business transaction system. This can provide an even more secure studying environment for students, since debit card can be stolen and use within the school too. With the fingerprint recognition system, the student’s fingerprint itself is the debit card. Nobody can steal it. Fingerprint scanning devices in hardware and recognition algorithm in software will be developed to verify and identify the identity of a student’s debit account through fingerprint scan. This will enable the student to do transaction by fingerprint scan in the school and does not need to go through the hassle of showing the debit card or paying by cash.

The paper is organized in the following way: Section II will be briefly comments on the fingerprint recognition school debit transaction system. Section III presents the proposed Hough Transform Minutiae Pairing Fingerprint Matching (HTMP) technique applies in identifying the correct person and section IV reports some experimental results. Finally, in section V, some conclusion and envision future developments is drawn.

2. Fingerprint Recognition School Debit Transaction System Design

This section outlines the system design for the fingerprint recognition school debit transaction system. It consists of the hardware architecture and software modules of the system as discuss in section 2.1 and section 2.2 below.

2.1 Hardware Architecture

Figure 1 shows the hardware architecture for the proposed fingerprint recognition school debit transaction system. The overall system consists of fingerprint collection module and PC/tablets placed at each shop/stall, all linked to a centre hub (server) with students’ information database for info matching and business transaction.

![Figure 1. Fingerprint Recognition School Debit Transaction System](image)

2.1.1 R305 Optical Fingerprint Module

It is an optical biometric fingerprint sensor with a TTL UART interface for direct connection to the PC. The user is allowed to store fingerprint data and verify identity with the module. The module consists of two main function which are enrolment and matching of fingerprint. However, in this project, only the enrolment of fingerprint function is in used. The build in fingerprint matching function of R305 is slow when datasets achieving 1000 or more. There is an advance algorithm, namely the Hough Transform Minutiae Pairing (HTMP) fingerprint matching technique is proposed in the computing side (PC/tablet) to run the fingerprint matching task. Besides that, the optical fingerprint module will capture the image of a finger by utilizing the light ray. However, the image of the fingerprint can be affected by external environment such as dirt, wet, quality of skin and humidity. It will be more easy to study and trouble shoot the fingerprint mismatch in the proposed external matching algorithm (HTMP), rather than using the R305 build in matching algorithm.
2.1.2 Arduino UNO

The R305 fingerprint module is interfacing by Arduino UNO board. There are several types of Arduino board such as Uno, Mega, Nano, and etc. However, Arduino Uno which based on ATmega328 microcontroller was selected due to its inexpensive cost, cross platform, simple and clear programming environment, with open source and extensive software, together with large support of community. The proposed Arduino UNO board is supplied with multiple sets of digital and analog input/output pins. The operating voltage of the Arduino Uno will be 9V by connecting to the power supply of PC/tablet. The four digital pins (TXD, RXD, VIN and GND) of the R305 fingerprint module are connected to the Arduino UNO board, as shown in Figure 3 below. The Transmit Data (TXD) pin is connected to pin D3 of Arduino UNO board for data output, the Receive Data (RXD) pin is connected to pin D2 of Arduino UNO board for data input. The Input Voltage (VIN) pin is connected to pin 5V of Arduino UNO board for a constant 5V supply to fingerprint module, and the Ground (GND) pin is connected to pin GND of Arduino UNO board for ground.

2.1.3 Functional Push Buttons

There will be three push buttons as shown in Figure 4, placed on the fingerprint collection module for three important functions, namely: Enrolment, Verification and Delete. The three buttons are connected each with a 1kΩ pull up resistor to the Arduino UNO board.

2.1.4 LED and LCD Display

One red LED, one green LED and three yellow LEDs are used as indicators on the fingerprint collection module. The three yellow LEDs are connected to pin number 12, 10 and 4, as shown in Figure 5, indicate the mode selection of Enrolment task, Verification task and Delete task respectively. The red LED is connected to digital pin 13 to indicate task failure, the green LED is connected to digital pin 11 to indicate task successful. The (I²C) LCD display is used to display the short messages to the shopkeepers about the task execution of the fingerprint collection module, as shown in Figure 6 below.
2.1.5 PC/Tablet

The PC, laptop or tablet will read in fingerprint signals transferred from the Arduino UNO and perform the fingerprint image processing for users’ identity matching. It comes with Graphic User Interface to registration page, selling products menus, purchase histories etc. Other than that, it can display the product database, and allow other operations such as viewing employees clock in-out times, sales report, etc.

2.1.6 Server

The server work as a centre hub which manages the access of multiple stall stations to a centralized resource (users’ personal information, databases of selling products name lists, price, credit balance, top-up and purchase histories etc.)

2.2 Software Implementation

The fingerprint based school debit transaction system begin with a graphical user interface that authorize the users to register their personal information into the database 1. After that, user is required to enrol their fingerprint into the system for future verification purpose. When the user wishes to proceed for credit transaction (top-up credit or purchase items/services), a verification of fingerprint is needed. There are only two possibilities for the verification results: Successful or Fail. Only the user with a valid fingerprint stored in the database can proceed to further operations such as top-up credit or purchase items/services. After the transactions being performed, the system will update the latest account balance into the database. The overall software architecture for fingerprint based school debit transaction system is shown in Figure 7 below.

2.2.1 Activity Diagrams

Activity diagrams are used to demonstrate the processes carried out in the system. Generally, there are five activity diagrams used in the proposed fingerprint based school debit transaction system: (1) Activity diagram of fingerprint enrolment, (2) Activity diagram for fingerprint verification, (3) Activity diagram for top-up process, (4) Activity diagram of transaction process (5) Activity diagram for checking purchase history.

The fingerprint enrolment needs at least two identical fingerprint inputs for the sake of wipe out potential errors during the feature extraction process. The image processor (PC/laptop/tablet) will match the fingerprints to determine whether the two inputs are from the same user’s finger. If yes, the template will be saved. Else, if the second fingerprint input is not match with the initial one, the system might not generate the template. The complete fingerprint enrolment process is shown in Figure 8.

For fingerprint verification process, the quality of the fingerprint will be enhancing by some pre-processing steps like classifying fingerprint image into the 8 major pattern categories, identify the essence point in the fingerprint image and crop the core region concentrated in the essence point, so that the important features like minutiae, ridges and bifurcation points can be extracted for future matching. The fingerprint matching algorithm will further discuss in Section 3. If the input fingerprint matches with the template stored in the database, the LCD screen will display the user identity for shopkeeper to further verify with user. However, if the input fingerprint does not match any of the template stored in the database, the LCD will not display any user identity, and perhaps will show message “Not found in database”. The whole fingerprint verification process is shown in Figure 9.

If the input fingerprint is successfully matched with the template stored in the fingerprint database, the user can carry out functions like topping up their debit account, paying for their meals, groceries, stationaries, services etc. and checking their top-up and purchase history. The whole process for the functions above is graphically illustrated in Figure 10, Figure 11 and Figure 12 respectively.
Figure 8. Activity diagram of fingerprint enrolment

Figure 9. Activity diagram for fingerprint verification

Figure 10. Activity diagram for top-up process

Figure 11. Activity diagram of transaction process
2.2.2 GUI Design and Database Software

In this sub-section, the software implementation and procedures for designing a user interface is discussed. The Graphical User Interface (GUI) will be created on Microsoft Visual Studio 2017 as it can be easily created by clicking and dragging the desired components such as label, text box, buttons, check box and data grid into the GUI layout form. Figure 13 (a) shows a blank Microsoft Visual Studio 2017 GUI layout form and Figure 13 (b) shows its corresponding Toolbox. The component parameters and properties such as appearance, data and layout can be checked and changed by double clicking on the components. Furthermore, the database connection can be checked from the server explorer. This assures that all the data is entered into the database table. Figure 13 (c) shows the Microsoft Visual Studio 2017 Properties box and Figure 13 (d) shows the Microsoft Visual Studio 2017 Server Explorer. The completed design of the GUI will be shown in Section 4.

The database of the proposed fingerprint based school debit transaction system is built by Microsoft SQL Server Management Studio. The database of this project is to store and retrieving data such as personal information and the account balance. There will be total four tables of the product. Each of the tables is used to store and manage the collected data that are inserted from the GUI application, and it will be retrieved when it is requested by users. The connectivity of the database of the database is explained below. First, thee relational database management system is connected to the ASUS server host after the SQL Server Management Studio has been assessed. Then, a new database from the Object Explorer is created. The tables in the database can be used to assign and manage different input data directing from the GUI application. After a new table has been created, a name is assigned to each of the column in that table. Figure 14 shows an example of the created database.

3. Hough Transform Minutiae Pairing Fingerprint Matching (HTMP) Technique

The Hough Transform Minutiae Pairing (HTMP) fin-
gerprint matching technique is proposed to the develop
gerprint based school debit transaction system and it is
run by the following six steps:

Step 1: Scan Live Fingerprint: Retrieve user’s finger
print image using R305-optical fingerprint module.

Step 2: Classify Fingerprint Image: Classify the fin-
gerprint image into any of the below eight categories: (i)
Plain Arch (ii) Tented Arch (iii) Ulnar Loop (iv) Radial
Loop (v) Plain Whorl (vi) Central Pocket Loop Whorl (vii)
Double Loop Whorl and (viii) Accidental Loop Whorl, as
depicted in Figure 15.

Step 3: Identify Region of Interest: identify the essence
point in the fingerprint image and crop the core region
concentrated in the essence point.

Step 4: Enroll Fingerprint Minutiae: extract two
minutiae spot sets M and N from two fingerprint im-
ages (database and inquiry) with undisclosed scale,
rotation and translations by the following notations:

\[ M = \{ (m^1_x, m^1_y, \gamma^1), \ldots, (m^P_x, m^P_y, \gamma^P) \} \]

\[ N = \{ (n^1_x, n^1_y, \delta^1), \ldots, (n^Q_x, n^Q_y, \delta^Q) \} \]

where \( P \) and \( Q \) are the total number of minutiae in set M and set N re-
spectively. \( (m^i_x, m^i_y, \gamma^i) \) and \( (n^i_x, n^i_y, \delta^i) \) are those three
features (x-position, y-position, orientation) correlated
with the i-th minutiae in set M and set N respectively.

![Figure 15. Fingerprint patterns](image)

Step 5: Determine Rotation and Translation Pa-
rameters: the transformation orientation function:

\[ G_{s, \theta, \Delta x, \Delta y} : R^2 \rightarrow R^2 \]

is given by [14],

\[ G_{s, \theta, \Delta x, \Delta y}(x, y) = s \begin{pmatrix}
\cos \theta & \sin \theta \\
-\sin \theta & \cos \theta
\end{pmatrix} \begin{pmatrix}
x \\
y
\end{pmatrix} + \begin{pmatrix}
\Delta x \\
\Delta y
\end{pmatrix} \]

where \( s, \theta, (\Delta x, \Delta y) \) are the scale, rotation and trans-
lation parameters correspondingly. For fingerprint authen-
tication/identification, the scaling factor \( s \) is set to unity,
due to the reason that the same device is used to capture
fingerprint images for both the offline processing stage
and online authentication stage. The generalized Hough
Transform [15] is applied to determine those parameters.
The entry \( E(l, p, q) \) sum up the verification of the orien-
tation transformation \( G_{\theta_l, \Delta x^p, \Delta y^p} \), where \( (\theta_l, \Delta x^p, \Delta y^p) \)
are the quantized values of \( (\theta, \Delta x, \Delta y) \) correspondingly.
The normalized \( E(l, p, q) \) in the range from 0 to 1 is
represented by \( f(\theta, x, y) \) and is treated as the proba-
bility density function for \( \theta, x, y \) transformation parameters.
\( (\theta, x, y) \) are independent from each other and can be es-
imated separately, hence \( f(\theta, x, y) \) can be re-structured as:

\[ f(\theta, x, y) = f_\theta(\theta) \ast f_x(x) \ast f_y(y) \quad (2) \]

(1) Rotation Parameter: Let \( O_d = (O^1_d, \ldots, O^P_d) \) be
the orientation field from the database fingerprint image and
\( O_i = (O^1_i, \ldots, O^Q_i) \) be the orientation field from the in-
quiry fingerprint image, where \( P_d \) and \( P_i \) are the lengths
of the \( O_d \) and \( O_i \) arrays respectively. The generalized
Hough Transform based method to estimate the rotation
parameter \( \theta \) consists of following 2 main steps:

(a) Estimate the probability density function of the ro-
tation parameter \( f_\theta(\theta) \)

(b) Search the correct rotation parameter of the two
transformation among the two fingerprint images based on
the results obtain in (a.)

An accumulator array \( E(l) \) is used to gather the ver-
ification for each possible rotation by 1 degree, whereby
\( l = O^p_d - O^q_i \) degree which map \( O^q_i \) to \( O^p_d \). The correct
rotation transformation among two fingerprint images is
computed by mass center [14]:

\[ \mu_\lambda(\theta) = \frac{\sum_{l \in \lambda} l \times f_\theta(l)}{\sum_{l \in \lambda} f_\theta(l)} \]

where \( \lambda \) is the densest interval among the extracted mi-
nutiae from the collected fingerprint images

(2) Translation Parameter: the computation of the trans-
lation parameters \( (t_x, t_y) \) can be done with the rotation
parameter \( \theta \) obtained above. Consider that the minutiae
set M and N are extracted from the database and inquiry fingerprints correspondingly, utilizing the determined rotation transformation $G_\theta$ upon the minutiae in set N, a new rotated version of the N point set, $N'$ can be acquired. The following notation are in used:

$$N' = \left\{ (n_{x_1}^{r,j},n_{y_1}^{r,j},\delta_{r_1}^{r,j}), \ldots (n_{x_Q}^{r,j},n_{y_Q}^{r,j},\delta_{r_Q}^{r,j}) \right\}$$

where $(n_{x_i}^{r,j},n_{y_i}^{r,j},\delta_{r_i}^{r,j})$ are the three features (spatial, position, orientation) related to the i-th minutiae in set $N'$. It can be calculated by [14]:

$$\begin{pmatrix} n_{x_i}^{r,j} \\ n_{y_i}^{r,j} \\ \delta_{r_i}^{r,j} \end{pmatrix} = \begin{pmatrix} \cos \theta & -\sin \theta & 0 \\ \sin \theta & \cos \theta & 0 \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} n_{x_i}^{q,j} \\ n_{y_i}^{q,j} \\ \delta_{q,j} \end{pmatrix} + \begin{pmatrix} 0 \\ 0 \\ \theta \end{pmatrix}$$  \hspace{1cm} (4)

where $(n_{x_i}^{q,j},n_{y_i}^{q,j},\delta_{q,j})$ is the i-th minutiae in set N, $\theta$ is the estimated rotation angle. Two minutiae points sets M and $N'$ are used to calculate the translation parameters $(t_x, t_y)$. The steps for calculating x-translation, $t_x$:

(a) Estimate the probability density function of the x-translation parameter $f_x(x)$

(b) Calculate the x-translation, $t_x$ with $f_x(x)$.

An accumulator array $E(p)$ is used to gather the verification for each possible x-translation, whereby $p = m_{x_i}^{l} - n_{x_i}^{r,j}$ is the x-translation which map $n_{x_i}^{r,j}$ to $m_{x_i}^{l}$. $m_{x_i}^{l}$ is the x-coordinate for the i-th minutiae in set M and $n_{x_i}^{r,j}$ is the x-coordinate for the j-th point in set $N'$. The correct x-translation transformation among two fingerprint images is computed by mass center [14]:

$$\mu_{\lambda(x)} = \frac{\sum_{p \in \lambda} p \times f_x(p)}{\sum_{p \in \lambda} f_x(p)}$$ \hspace{1cm} (5)

where $\lambda$ is the densest interval among the extracted minutiae from the collected fingerprint images.

The steps for calculating y-translation, $t_y$ are identical with that of calculating x-translation, $t_x$. The correct y-translation transformation among two fingerprint images is computed by mass center [14]:

$$\mu_{\lambda(y)} = \frac{\sum_{q \in \lambda} q \times f_y(q)}{\sum_{q \in \lambda} f_y(q)}$$ \hspace{1cm} (6)

whereby $q = m_{y_i}^{l} - n_{y_i}^{r,j}$ is the y-translation which map $n_{y_i}^{r,j}$ to $m_{y_i}^{l}$. $m_{y_i}^{l}$ is the y-coordinate for the i-th minutiae in set M and $n_{y_i}^{r,j}$ is the y-coordinate for the j-th point in set $N'$. The steps for calculating x-translation, $t_x$:

Step 6: Set Threshold to Compute Matching Score: Pair up the minutiae set if the two fingerprint images' features or components ($\mu_{\lambda(x)}, \mu_{\lambda(q)}/\mu_{\lambda(y)}$) are identical or within a range of tolerance. A tolerance box is generated throughout each minutiae feature for coping with the shifting in the minutiae pairs. The minutiae pairs are gathered among the pairs that fulfill the below geometric constraints [14]:

(a) The two minutiae’s Euclidean distance does not exceed a certain value $\Delta d$.

(b) The two minutiae directions’ angular difference below a certain tolerance $\Delta \theta$.

(c) Supposing that in excess of one pairs situate in the same bounding box, the two minutiae with the minimum Euclidean distance opt as the matched pair.

Concerning to weight out the similarity among two fingerprints, a similarity level measurement method applying the matching score $\psi_s$ is adopted, with the below formula [14]:

$$\psi_s = \frac{N_{pair}}{\max\{P, Q\}}$$ \hspace{1cm} (7)

where $N_{pair}$ is the number of matched minutiae pairs, P and Q are the total number of minutiae extracted from the database and inquiry fingerprint images correspondingly. $\psi_s$ is with value ranging from 0 to 1. If $\psi_s$ is tends to 0 implies that the two fingerprints are non-matching, else if $\psi_s$ is tends to 1 implies that the two fingerprints are good match.

4. Experimental Results

In this section, the application of the proposed fingerprint school debit transaction system will be illustrated. It will cover the product overview, test run results and the product survey analysis. The fingerprint school debit transaction system was tested in an institution of higher learning within Malaysia, who wants to remain anonymous.
4.1 Product Overview

The final prototype of the fingerprint school debit transaction system is shown in Figure 16. The circuit board and Arduino UNO microcontroller module are stored inside an external custom made casing. The function of all the buttons are clearly labelled with laminated instruction signs. The LCD and LED will begin to operate once the USB cable is connected to PC/laptop/tablet. When the fingerprint verification process is successful, the green LED will light up, whereas if unsuccessful fingerprint verification process detected, the red LED will be light up.

Figure 16. Final Prototype of the Fingerprint School Debit Transaction System (Fingerprint Collection Module)

The Admin Login GUI page is shown in Figure 17. This is the main page of the fingerprint school debit transaction system. Only the related school shopkeepers (Canteen, Cafeteria, Mini Mart, Printing shop, laundry shop, computer shop etc.) have their own username and password to login to the server to perform the business transaction (transfer students deposited money into their account). This is to ensure the privacy and confidentiality of every shopkeeper.

Figure 17. Admin Login GUI page

The first important step for the system to work is to enrol the students’ (users’) fingerprint and personal information into the system. The registration page is shown in Figure 18. The basic information to insert is course, phone number, full name, gender and age. After inserting all the relevant information, the “ADD” button is pressed to enrol in the system. In this case, the system will generate an ID number for that particular student. Moreover, the system can be used to update the latest information or delete the student’s previous account.

Next, students are instructed to enrol their fingerprint with the assigned identification number in the fingerprint collection module. The “Enrol” button must press to enrol a fingerprint, the message “Please insert your ID” will be displayed on LCD screen, as shown in Figure 19(a). Once the ID number has been inserted, the student may place his/her finger on the fingerprint module to scan fingerprints. The student must place his/her finger twice in each registration process, because the second fingerprint input is required to compare and check with the initial template to ensure that both fingerprint inputs are matched. The system will then display “Print Matched, Enrol successful” to indicate a success case (as shown in Figure 19(c). Else it will display “Error” in the LCD screen for fail case. Students who have successfully enrolled their fingerprint into the database system may now start deposit /top up credit into the database. The top-up page is shown in Figure 19d.

Figure 18. Registration Page at Server
Students may start purchasing meals, goods, services within the school after enrolled and deposited credit into the database. A canteen case is chosen for further studies. Figure 20a shows the Meal GUI page and Figure 20b shows the Drinks GUI page of the canteen menu page. The meals and drinks selected by the students are later added to their shopping list, under Mycart GUI page, as shown in Figure 20c. This page shows the price and quantity of items ordered by students.

In order to check out the items, students must authenticate their identity by evaluating their fingerprint for making payment. Students are required to press the “Verify” button on the fingerprint collection module, as shown in Figure 20d. After the “Verify” button pressed, the LCD screen will display the message “Waiting for valid fingerprint”, as shown in Figure 20e, while processing the fingerprint to seek for the correct students’ ID. The LCD screen will display the message “Found ID #.” for successful verification attempt, as shown in Figure 20f.

On the fingerprint collection module, the red LED will initially illuminate to indicate that there is no finger place on the sensor. The green LED will light up once the students’ fingerprint had been identified. The LCD screen will display the students’ identification number and the accuracy of the matching fingerprint. Only student who has successfully obtained his/her identification number can make transaction. The canteen operator will insert the students’ identification number to complete the payment process.
4.2 Test Run Results

The fingerprint school debit transaction system was test run in the canteen of the institution of higher learning. The experiment tested between 1,000 different students and staff. Each person must contribute 2 fingerprint inputs, which are thumb and index finger during the experiment. Moreover, each fingerprint entry will be tested with total number of 5 times. There will be a total of 10,000 attempts in this experiment. The main experiment objective is to test the reliability of this fingerprint recognition system by calculating the successful authentication rate between 10,000 attempts. The rate of accuracy will be calculated with the below formula:

\[
\text{Rate of Accuracy} = \left( \frac{\text{Successful Attempt}}{\text{Total Attempt}} \right) \times 100\% \quad (8)
\]

Table 1 below shows the number of successful authentication in each of the thumb and index finger attempts. The total number of successful attempts in this authentication experiment is 9,090. Therefore, the accuracy rate for this system is 90.9% by using equation (8). Figure 21a shows the failure rate between the thumb and index finger and Figure 21b shows the failure rate between the (<2) attempts and (>2) attempts.

The pie chart in Figure 21a shows clearly that index finger has higher unsuccessful attempt rate (60.55%) compare to thumb finger (39.45%). The pie chart in Figure 21b shows that most of the unsuccessful attempts took place in the first two attempts of the experiment. It has failure rate up to 79.23% in the first two attempts of the authentication process. However, there is a drastic drop after the first two attempts (20.77%).

There are several reasons that could affect the accuracy of the authentication process such as the finger pressure exerted on the sensor and the immobility and fixed posture of finger during verification. Besides that, finger’s skin conditions such as dry, moisture and dirt may also affect the authentication result. Thus, it can conclude that the initial failure rate was solely caused by human factor.

Table 1. Results of Fingerprint Authentication Attempts

<table>
<thead>
<tr>
<th>Finger Types</th>
<th>No. of Authentication Attempts</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Thumb</td>
<td>761</td>
</tr>
<tr>
<td>Index Finger</td>
<td>679</td>
</tr>
<tr>
<td>Total Successful</td>
<td>1,440</td>
</tr>
<tr>
<td>Total Unsuccessful</td>
<td>560</td>
</tr>
</tbody>
</table>

DOI: https://doi.org/10.30564/aia.v1i2.1202
4.3 Product Survey Analysis

For the 1,000 participated students and staff in testing the fingerprint collection module, a survey was conducted onto them to determine the awareness and market value of the fingerprint based school debit transaction system. The questionnaire and the results are shown in Figure 22. Generally, majority of the respondents agreed that all schools should have a cashless future and 40% of them have heard about biometric identification, particularly in fingerprint technology. In addition, 98% of them agreed that a fingerprint based debit transaction system can eliminate the need for a student to carry cards and remember their password/identification numbers. Most of them are willing to replace the conventional payment method with this new fingerprint based debit transaction system. Furthermore, 82% of the respondents believe that the appropriate time taken to identify the fingerprints should be less than 1 minute (our proposed system current achievement is 30 second plus). Furthermore, most respondent do not believe that the use of fingerprints would be an invasion of privacy and are willing to trust the fingerprint based debit transaction system if it is introduced in the school business area.
5. Conclusion

A fingerprint-based school debit transaction system is developed to promote a smooth flow and cashless transaction environment within the school. In this case, it makes all the procedures and step become more convenient and efficient. Furthermore, the implementation of fingerprint-based transaction system can totally avoid using cash money as well as prevent issues like debit card get lost or stolen. All of the transactions made within the school will be independent of PIN and cards. Therefore, with this cashless payment system, all the money can be safely secured in the student’s account. Moreover, one of the highlights of this system is able to trace back all the purchase history. This function can help the parent to monitor and restrict their children from consuming any unhealthy diet and junk foods. Thus, parent can ensure that their children’s money is being spent on the right intention. In addition, a survey was conducted with 1,000 students and staff in the corresponding institution of higher learning, and majority of them agreed that all schools should be pursuing a cashless future and willing to use fingerprint-based transaction system.

The proposed fingerprint-based school debit transaction system does have some limitation. It depends critically on the quality of the fingerprint’s image. The resolution of the fingerprint’s image has a vital influence on the accuracy of the matching system. The current optical fingerprint module might not be able to extract the important features from the fingerprint if the input is in extremely low quality (blur user’s fingerprint surface). Therefor it can lead to rejection or acceptance. Furthermore, the pressure exerted and the finger’s skin condition are also constraints to the current system.

The current fingerprint collection module is powered by electricity from the PC/laptop/tablet by each shop with the school. However, if there is a power failure occurs, the system will stop working. In this case, it will restrict the registration and verification process, and may stop other users from making payment with the system. An independent power source will be developed in future to prevent such incidents cause by power failure occurs. At this moment, the system only works in an offline mode within school. For instance, it does not allow parents to check the purchase history and credit balance via online. In addition, the proposed system does not support online banking yet. Parents have to come to the finance department to transfer or deposit funds to their children’s debit account. In future, the debit transaction system will be integrated and corporates with several banks to allow online banking transaction.

References


Using the CVP Traffic Detection Model at Road-Section Applies to Traffic Information Collection and Monitor — the Case Study

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1. Introduction

Advanced traffic information collection can provide an efficient, reliable, instant and mass traffic info at instant governmental road information publication. It can also be used for traffic managing strategies, monitor and control. This paper provides a trial area at Tai # 2 Gee-Jing Roadway connecting to Wan-Li section on the fiscal year of 2017-2018. This project provides a new increased CVP detecting road-section (RS) from Man-flow turning into vehicle-flow Model applying to Traffic Information Collection and Monitor for 7 days per week with 5 minutes interval traffic info. Via the new improved man-flow turning to vehicle flow model, we proposed a Long-Short Time Memory (LTSM) recurrent neural network (RNN), to rapidly setup several trained into big data model for regular daytime.

This paper proposes a using Cellular-Based Vehicle Probe (CVP) at road-section (RS) method to detect and setup a model for traffic flow information (info) collection and monitor. There are multiple traffic collection devices including CVP, ETC-Based Vehicle Probe (EVP), Vehicle Detector (VD), and CCTV as traffic resources to serve as road condition info for predicting the traffic jam problem, monitor and control. The main project has been applied at Tai # 2 Gee-Jing roadway connects to Wan-Li section as a trial field on fiscal year of 2017-2018. This paper proposes a man-flow turning into traffic-flow with Long-Short Time Memory (LTSM) from recurrent neural network (RNN) model. We also provide a model verification and validation methodology with RNN for cross verification of system performance.
Figure 2 (a) & (b) and 5 minutes traffic info for CVP with RS traffic travelling time, vehicle flow, and RS-turning vector updated periodically. Figure 3 shows the detected CVP Road Condition detection flowchart. The flowchart is designed to have 5 procedures, which is the first step, CVP signal command original; data collection; the second step is related traffic info collection, like CVP, EVP, VD, and CCTV. The third step is merged from step 1 and step 2. Then, the major work of this project is traffic flow trajectory modelling setup and Analysis. The deployed at the trial region is shown at Figure 2a & b.

Table 1 shows the peak and non-peak traffic modes at different types of Intersection. Table 1 shows the peak and non-peak traffic modes at different types of Intersection.

![Figure 1. CVP Road Condition Detection Flowchart](image1)

Figure 1. CVP Road Condition Detection Flowchart

![Figure 2 (a). 2017 de facto CVP Detecting RS Demo Project](image2)

Figure 2 (a). 2017 de facto CVP Detecting RS Demo Project

![Figure 2 (b). 2018 newly increased CVP Detecting RS Demo Project](image3)

Figure 2 (b). 2018 newly increased CVP Detecting RS Demo Project

Figure 2 (a) & (b) and 5 minutes traffic info for CVP with RS traffic travelling time, vehicle flow, and RS-turning vector updated periodically. Figure 3 shows the detected CVP Road Condition detection flowchart. The flowchart is designed to have 5 procedures, which is the first step, CVP signal command original; data collection; the second step is related traffic info collection, like CVP, EVP, VD, and CCTV. The third step is merged from step 1 and step 2. Then, the major work of this project is traffic flow trajectory modelling setup and Analysis. The deployed at the trial region is shown at Figure 2a & b.

![Figure 3. Signal timing at selected intersection points](image4)

Figure 3. Signal timing at selected intersection points

Table 1. Peak and Non-peak Traffic modes at different types of Intersection

<table>
<thead>
<tr>
<th>Types of Intersection</th>
<th>Peak Traffic</th>
<th>Non-Peak Traffic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Morning</td>
<td>5:00 AM</td>
<td>7:00 AM</td>
</tr>
<tr>
<td>Afternoon</td>
<td>12:00 PM</td>
<td>2:00 PM</td>
</tr>
<tr>
<td>Evening</td>
<td>7:00 PM</td>
<td>9:00 PM</td>
</tr>
<tr>
<td>Night</td>
<td>11:00 PM</td>
<td>1:00 AM</td>
</tr>
</tbody>
</table>

2. CVP Road Condition Detection and Model Setup

Road condition detection is defined as to include the traffic flow and travelling time detection together. Based on the traffic flow volume, one can postulate the instant signaling data and related position of actual position. We can use statistics to calculate each individual timing on the certain road-section (RS) for every customer. Then, we use customer volume and actual real traffic volume to setup a postulated model. Thus, we can probably postulate this RS traffic flow volume. Simultaneously, based on one customer’s adjacent instant signal interval difference, one can postulate the traffic volume at that RS moving traffic flow. When we calculate all of the mobile customers individually contribute the traffic volume by statistics, one can induct an embedded road-user related reference value at RS traffic volume. However, Telecom signal will have an averaged 5 minutes delay from signal reception, cleaning, making a pair, model analysis, and providing a operation result.
2.1 Traffic-flow Model Setup and Analysis

Via the mobile signal info, we can estimate the traffic-flow volume at that RS from the historical info by neural network training data module to postulate the RS traffic volume. When the system receives the instant traffic mobile data, one can use this module to postulate traffic-flow volume. Furthermore, when each accumulated period of time from the historical data, one can increase the accuracy of traffic-flow volume. For analyzing the CVP road-condition to postulate the trend of traffic-flow volume. This paper uses the supervised learning from machine learning model. The training procedure is to tell the true value of that RS to let them learn themselves. The training model is used to postulate the future change of traffic flow. This paper uses the model of long short-term memory, (LSTM) to be an extended model, as shown in Figure 4 for system architecture. It is an artificially recurrent neural network (RNN) architecture. LSTM has feedback connections and not only process single data points (such as images), but also entire sequences of data. The compact forms of the equation for the forward pass of an LSTM with a forget gate are: [7,8]

\[
\begin{align*}
    f_t &= \text{sigmoid}(W_f x_t + U_f h_{t-1} + b_f) \\
    i_t &= \text{sigmoid}(W_i x_t + U_i h_{t-1} + b_i) \\
    o_t &= \text{sigmoid}(W_o x_t + U_o h_{t-1} + b_o) \\
    c_t &= f_t c_{t-1} + i_t \sigma(W_c x_t + U_c h_{t-1} + b_c) \\
    h_t &= o_t \sigma(c_t)
\end{align*}
\]

(1) (2) (3) (4) (5)

Figure 4. LSTM system architecture

Where the initial values are \( c_0 = 0 \) and \( h_0 = 0 \) and the operator \( o \) denotes the Hadamard product (element-wise product). The subscripts \( t \) indexes the time step. LSTM handles the cell memory to be a controlled gate state. That is it can delete, increase, and output the message. \( f_t \) is defined as forget gate, which message is deleted, increased, and outputted from cell. And, \( i_t \) is defined as the input gate which message is deleted, increased, and inputted from cell. \( o_t \) is defined as the output gate which message is deleted, increased, and outputted from cell.

It can memorize the time-series info of traffic volume and serve as the reference point of next time stamp. Compared with RNN model, LSTM model has more gates such as forget gate, input gate, and output gate. They can be used as a more complicated parameters to be used memorize and forget to reach a better postulated capability. We compare the experimental models of CNN, BPNN, and LSTM from simulation. The LSTM has a better result.

2.2 Traffic-flow Estimation

Via the mobile signal info, this paper proposes a postulated estimated traffic-flow volume estimation from neural network training RS during a historical info module over a period of time. For accumulated historical data, one can reconstructed the model of RS to increase the accuracy of traffic-flow estimation.

To analyze the trend change of road condition for the variation of CVP to postulate the traffic-flow. This paper adopts the supervised learning style of machine learning. That is at the training level to input the true value of traffic-flow to let self-adjust at the training model. One just see the MSE error of training model enter the allowance range to reach the accepted setup model.

We can use this model to postulate the variation of traffic flow in the future. In the model, we propose the major structure of RNN because the info of time-series model can record the past info change from memory and use this model to postulate the future change of traffic flow. There are five major elements in the RNN model:

1. The input of RNN is an \( X \), which is the Telecom signal info. Those contain man-flow, date, time (5 minutes as one units), and traffic-flow, etc.
2. The output of RNN is a postulated traffic-flow.
3. The parameters of RNN are the weightings of \( U, V, W \) with the final recursive trained values.
4. The hidden state is to represent the RNN’s memory’s \( S \).
5. A series of continued periods of time from \( t-1 \), \( t \), \( t+1 \).
6. The traffic-flow postulated model is based on the time-series recurrent neural network, which is based on the info of CVP, can be regarded the input of RNN and the trend of traffic-flow is regarded as the output of RNN; where the hidden state at the time instant of \( t-1 \) and the hidden state of time \( t \). The formula is written as

\[
S_t = f([U]X_t + [W]S_{t-1})
\]

The Timing Sequence of RNN can be depicted as Figure 5.
Because the traffic-flow is a continuous state; thus, it is quite to refer the past-timing state to change the current state to reach a more postulated state for the trend of variation. To reduce the effects of the irregular states, one needs to pretreat the traffic info. The pretreatment of traffic info include the info become a time-series info; which contains 4 stages, sort out time-series info, combine RS, info standardization, and correspond to CVP which contains 4 stages, sort out time-series info, come-
bine RS, info standardization, and correspond to CVP info, respectively. The total flowchart is depicted as figure 6.

Figure 6. Pretreatment of Man-flow turning into traf-
ic-flow

The procedure is arranged into the following stages:
(1) The 1st stage:
The 1st stage is to arrange time-series data and telecom user individual time-series data.
(2) The 2nd stage:
The 2nd stage is to combine RS. At first is to investigate the path road section in correspondence table and find out the needed RS info of required path and combine them and delete the outlier’s value and vacant value.
(3) The 3rd stage:
The 3rd stage is to standardize data and proceed the data to meet standard normal distribution. That is, the mean value is 0, standard deviation error is 1, and, its transfer function is

$$z = \frac{(x - \mu)}{\sigma} \quad (7)$$

where x is needed to be standardized score, $\mu$ is the average value, $\sigma$ is the standard error and $\sigma \neq 0$, z represents the original score and the distance of population mean.
(4) The 4th stage:
The 4th stage is the correspondence of EVP info and produces the training data and test data. Then, provide the CVP man-flow turning into traffic-flow model with cross-validation by RNN. The flowchart of construction of model and testing procedure is given at Figure 7.

Figure 7. Man-flow turning into traffic-flow postulated framework

The framework of human-flow given at Figure 8 turning into vehicle-flow contains input layer, LSTM layer, hidden layer and output layer; where t represents time stamp, t-5, represents a priori 5 time stamp. X1 – Xt represents different characteristics, j1 to jn represents a hidden neural unit, y(t) represents the traffic-flow. At input layer, there are numerous characteristics such as the total signal numbers, travel time, a rough estimated total number of vehicles at that RS to be a set of input info. Furthermore, one-time estimated info needs to be input 6 sets data from (t0)–(t-5). After passing numerous long-term memory LSTM layer (as shown in Figure 7) and one hidden layer, it finally come out an estimated traffic-flow result. The flowchart of human-flow turning into vehicle-flow postulated model is given in Figure 8. Mainly, it can be casted with three folds. There are data model, training model, and testing model, respectively. Their responsibilities are data processing at data model, training model at trained model, and executing vehicle-flow postulation at testing model. At first, one comes into data model. They execute the judge of retrain to decide those data whether needs to be retrained. If, it is ‘yes’, it shall enter to query the historical data and proceed to handle data preprocessing. Via the training process, it is derived that (outliers) is produced in the original score and the distance of population mean. (4) The 4th stage:
model, one can get the extracted trained model to be the input model of neuron. After finishing the setup model, we store it into Application (AP) server. Furthermore, from the data model, one can acquire the necessary postulated CVP data and similarly proceed info pre-processing. Therefore, we can get a better capability from that kind of reference record. The individual training and parameter adjustment are important to reach an expected result.

\( y(t) \): the postulated traffic-flow at time-stamp \( t \).
\( x_1(t) \): the signal volume at time \( t \).
\( x_2(t) \): the CVP travelling time at time \( t \).
\( x_3(t) \): the calculated vehicle # at time \( t \).
\( x_4(t) \): the time-stamp at time \( t \).

**Figure 8.** The flowchart of man-flow turning into vehicle-flow model

### 3. Model Verification and Validation

#### 3.1 Signal Info Analysis

Although collecting traffic signaling info, it can promote the comprehensiveness and integrity of traveling info. However, the signal info is restricted to the law of Privacy Act. Due to different geometrical geospatial base station coverage, the market share of telecom operator and user habit are different. The possibility of accuracy of signal may produce prejudice. Therefore, we need to proceed model verification and validation through other transportation info to increase the accuracy of analytical results.

#### 3.2 Model Verification and Validation

The major RS have implanted electronic tag (eTag) detectors at the described deployed testing area. Thus, we want to use eTag’s info to proceed the verification and validation. This paper wants to use neural network to train the traffic-flow and use eTag detector RS to get cross validation and then calculate the error rate. If the error rate is larger enough than expected, we need to calibrate the module to reach the required accuracy. Furthermore, if the RS has no eTag detector or vehicle detector (VD), this project will use the traveling time from Google Map to be reference point for cross validation. About the Traffic-flow, we use AI image recognition to analyze the verification result.

This paper adopts the Lewis \(^7\) as the accuracy of evaluation criteria with MAPE. If, when the value of MAPE is between 10%-20%, it the model has high accuracy; when the value is 20%-50%, it means the prediction is reasonable.

<table>
<thead>
<tr>
<th>MAPE(%)</th>
<th>illustration</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;10</td>
<td>High accuracy prediction</td>
</tr>
<tr>
<td>10-20</td>
<td>Good prediction</td>
</tr>
<tr>
<td>20-50</td>
<td>Reasonable prediction</td>
</tr>
<tr>
<td>&gt;50</td>
<td>Not accuracy prediction</td>
</tr>
</tbody>
</table>

**Table 2. MAPE Evaluation criteria\(^7\)**

**Resource:** Lewis, C.D. (1982) \(^7\).

### 3.3 Cross Validation by Neural Network

The cross validation by RNN is given in Figure 3.1 (a). When the values of characteristics (include man-flow, date, time (5 minutes as a unit), traveling time, etc. the output of \( o \) for traffic-flow), times weighting \( W \) and add it together. Then, one can get the mapping value from activation (sigmoid) function \( f \); that is, the postulated traffic-flow volume. Then, we get final value of \( t \) via eTag detecting traffic-flow volume. Finally, we use the Adam\(^6\) algorithm to optimize the weightings of \( W \). The compared adjusted postulated value of a with true value of \( t \) is very close. This procedure is called a one-time calibration cycle. Through various trainings, the error of MSE will gradually reduce to the wanted results as shown in Figure 3.1 (b) at Gee-Gin 1st RD and 2nd RD during holiday model.

Figure 9 (a) and 9 (b) were executed at the last fiscal year of 2017 results. The weekday’s and holiday’s verification results of independent CVP model at Gee-Gin 1st RD-2nd RD were given respectively. The CVP traffic-flow verification at National HW #1 (From Bar-do to Mai-Gin RD) and the Manual Computing Unit (MCU) vs. CVP are given at Figure 10 (a) and 10 (b), respectively. The CVP traffic-flow postulated verified testing results at Gee-Gin RD at Table 2. Using EVP traffic-flow has the same result as CVP did it before. According to \(^7\), If, MAPE is less than 20%, it is a good prediction; the value of MAPE between 20~50% is a reasonable prediction. Thus, if we found that the newly increased detecting are has no the resources of EVP or VD at this project of 20, we will use CCTV instead as vehicle detector. Using image to transfer into traffic-flow and then compare/validate with the result with CVP model.
Table 2. The CVP traffic-flow postulated verified testing results at Gee-Gin RD

<table>
<thead>
<tr>
<th>Road Section</th>
<th>Independent Model</th>
<th>Shared Model</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Weekday MAPE</td>
<td>Holiday MAPE</td>
</tr>
<tr>
<td>Gee-Gin 1st RD-2nd RD</td>
<td>20.4%</td>
<td>15.5%</td>
</tr>
<tr>
<td>Gee-Gin 2nd RD-1st RD</td>
<td>18.9%</td>
<td>16.7%</td>
</tr>
<tr>
<td>Gee-Gin 3rd RD-2nd RD</td>
<td>14.4%</td>
<td>14.8%</td>
</tr>
<tr>
<td>Gee-Gin 2nd RD-3rd RD</td>
<td>18.2%</td>
<td>12.2%</td>
</tr>
<tr>
<td>Average</td>
<td>17.9%</td>
<td>14.8%</td>
</tr>
</tbody>
</table>

Figure 9 (a). the weekday’s verification result of independent CVP model at Gee-Gin 1st RD-2nd RD

Figure 9 (b). the holiday’s verification result of independent CVP model at Gee-Gin 1st RD-2nd RD

Figure 10 (a). The CVP traffic-flow verification at National HW #1 (From Bar-do to Mai-Gin RD)

Figure 10 (b). The Manual Computing Unit (MCU) vs. CVP

4. Conclusion

This paper proposes a using CVP method at RS to detect and setup a model for traffic flow info collection and monitor. Via the new improved man-flow turning to traffic-flow model, we proposed a LTSM with RNN to validate data model for regular daytime and peak and non-peak model for one year.

References


http://www.webpages.uidaho.edu/niatt_labmanual/chapters/trafficflowtheory/theoryandconcepts/GreenshieldsModel.htm


Application of Feature Curves and Shape Blending on Yacht Designing

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ABSTRACT

The global yacht market share and industry might expand continually since increasing people are willing to enjoy the yacht life in lower price nowadays while yacht activities were regards as a luxury activity in the past. Additionally, Taiwanese yacht manufacturers are well-known worldwide. They show excellent performances on the international annual rankings which implies Taiwan has excellent manufacturing technologies. However, Taiwanese manufacturers so far do not have a mature local design team. Therefore, this study goals to developing a systematic and objective design method for hull designing, which facilitates designers to design innovative yachts or create a series product with brand recognition. This study is divided into three parts: the first part is the investigation of the yachts market; the second is establishing a shape blending platform; the third is 3D forming. Finally, it is used the existing ship CAD software to design an innovative yacht based on the blended curves and then calculates its basic hydrostatic performance. This study provides a quantitative method to create a new form and to preserve the features for a brand. The exist yacht combines with other graphics to create a new form and maximizes the features of the original graphics.

1. Introduction

The yacht industry has had a stable demanding market in Europe and American. In recent years, the market for yachts, water amusement facilities and related industries has expanded depending on the people’s attention to leisure and entertainment. At present, the market capacity of the entire yacht industry in the world has exceeded USD 40 billion. Because of the world economic growth, the adjustment of the supply and demand scales, and the large number of old ships that need to be renewed, the overall demand for new ships will remain above a certain amount.

In the past, the yacht market was mainly distributed in North America, Europe, the Mediterranean, and New Zealand and Australia. With the rise of Dubai and China in recently, the demand in these two regions has grown rapidly. According to the global luxury yacht market survey report of Wise Guy Reports in 2017 [1], the market and growth trend of the future yacht industry are pointed out in the article because of the growth of millionaire families and the popularity of yachts as luxury sports. Thus, they have increased the market demand for private yachts. In addition, the market size in the following ten years is forecast to grow. By 2022, the global market can reach USD
Taiwan has a land area of about 36,000 km² where contains 31 yacht manufacturers and several of which are well-known worldwide. Our construction abilities have been favored around the world as well. Also the yacht manufacturers have been ranked in the global rankings recently. For example, Horizon Yachts has been ranked among the top ten manufacturers in the world for many years [2], and the Ocean Alexander, their number of yacht sales in 2016 also jumped to the fourth place in the world [3]. Those show Taiwanese yacht manufacturers have good reputation and are trusted by the international customers. However, Hsing Hang Marine states on its official website that the yachts produced by Taiwanese brand have not yet established their own distinctive style and brand characteristics. It is to say that Taiwan still hasn’t had its own yacht designer team. Most of the current ship plans are designed abroad. It is more difficult to develop the specific characteristics of the company.

In recent years, the manufacturers in Asia, such as South Korea and China, has also been continuously improving. Among these countries, China progress the most. In such a competitive environment, to maintain market share and the company’s profitability, Taiwan should break through the present operation modes of buying designs from abroad, and consider both future trends and one of the major features of Taiwan’s yacht industry. Adding features to their products highlights the values and significances behind the brand, while the product can be modularized, launched a series of products, and used for innovative design to increase recognition.

For many modern industries, the application and design extension of the brand series are the design direction of the new era. Yacht design can also use this concept to develop specialty products. The purpose of this study is to apply computer-aided design (CAD), systematic collaboration design, and the concept of brand feature to establish a system that is suitable for yacht design: develop new forms with the shape blending method, and judge the form with the principles of aesthetics, which is no longer relying on the designer's personal aesthetic to design the appearance of the yacht.

2. Related Works

2.1 Feature Forms and Aesthetics

In the product design, the appearance is the most basic form of a product. Regardless of the functions, the appearance has a tremendous influence on product sales, and sometimes plays an important role in whether the product can survive successfully [4-6]. Therefore, for mature product makers in the market, it is critical to stand out from the vast competitors in the case where the market share of the product is close to saturation and the product function and manufacturing technology are highly mature. When the brand is identified as a combination of elements, nothing can be ignored and the product conveys brand value through its appearance [7]. Overall, family features and the establishment of perceived connections between brands and consumers, with their design needs and business economic considerations, which may be a key factor in determining whether the product is sold successfully in the market.

Regarding the basic principle of aesthetics within the past past, Plato once stated that the thing with symmetry and regularity was beautiful. Most forms of beauty were possessed regular geometric shapes, conforming to the appearance of natural look. Birkhoff, the first scholar proposing quantitative beauty, applied the calculations of beauty on forming, poetry, music and other fields in his book Theory of Aesthetic Mathematic. He applied the above concepts to quantify the beauty by mathematics. [8] Later, Staudek used Birkhoff’s aesthetic formula to discuss the contribution of the measurement method regarding the aesthetic quantification of the appearance of the object and he verified it by vases (shown in Figure 1) [9]. The several types of characteristic points were created along the outline: terminal point, point of inflection, point of vertical tangent, and point of abrupt change in the direction of tangent. (Eq. (1)).

\[
M = \frac{H + V + P + T}{C}
\]

Where \( H \) is the number of the horizontal order, \( H \leq 4 \); \( V \) is the number of the vertical order, \( V \leq 4 \); \( P \) is the number of the proportional order, \( T \leq 4 \); \( C \) is the number of the tangent order, \( C \); is the complexity of the characteristic points and \( M \) is the aesthetic measure.

![Figure 1. Tomáš Staudek’s aesthetic measurement of vases](image)

Hsiao & Tian added the appropriate parameters into the original aesthetic measure. The new formula could
be applied to the 2D curves and 3D surface. Also, they proposed the measurement of the order, complexity, and aesthetics of the form as the evaluation basis of the form aesthetics for designers. Finally, it assisted designers to design new products. [10]

2.2 Shape Morphing

Shape homogenization and shape blending can generate new forms by interpolating and extrapolating the parameters of product forms, following certain rules to produce changes in the form, such as displacement, shrinkage, elongation, inversion, etc. Hui and Li in their feature-based shape blending study decomposed the form by semantics, components and points, thereby proposing features that could be blended and establish the correspondence between object features. The normalized weights were used in interpolation to find the corresponding relationship of feature points and to blend two models. [11] With the operations, the features of the form could be preserved during the blending process. In addition, the property of the interpolation was that the new blended feature was predictable when the two patterns were blending and tended to be similar with which pattern. After blending the 2D curves, the final 3D model was synthesized by the 2D curve boundary outlines. Finally, 3D model was generated. [12]

Hsiao et al used reverse engineering in combination with shape blending to create a reverse engineering methodology which could be applied to shape morphing. Combining with the existing CAD software provided industrial designers to structure ideation more quickly. The different part from the former study was the corresponding various point methods. Ray firing method calculated the angle between the end-to-center point line and the horizontal line through the center axis of the input shape. It was determined that the two end points were on the same ray diverging from the center point. When the difference between the two angles was the closest, it was regarded as a group of similar corresponding points. After the points were determined, blending operations could be performed. This study proposes four blending methods and uses different weights to adjust the specific gravity of the two components. [13-14]

3. Methodology

This study contains only determination of “design requirements and major dimensions” and “ship design and hydrostatic performance”. The rest is not considered in the study. The research process is mainly divided into two parts, as shown in Figure 2, which are the forming design and the conceptual yacht design. Finally, it is to present a new yacht with distinctive features and a system model that could be applied to design concept yachts.

Figure 2. The process of the research

3.1 Limitation and Specification

This study selects the yacht's feature form as the research object and focuses on the exterior design only although numerous factors have to be considered in designing a yacht. The color of the appearance is also excluded so all the yacht samples in the study show black and white. Except for the forming factors affected by regulations, the other factors might make a concession to the exterior design. The interior compartments will be referenced to the planning of the original yacht. Due to the huge scale of the yacht, this study focuses on the elements and features of the sideways. Other perspectives are used as an assistance. Finally, it presents in 3D computer model.

In this study, the rulers of an existing yacht are used as a reference to obtain a datum model. In order to simplify the research scale, few factors are taken into consideration, such as speed, stability, resistance, load, and buoyancy requirements. There is not a specific owner and shipyard, so the budget and the manufacturing technology cannot be confirmed, and this study doesn’t consider the main engine as the variable. Also, the overall cost and total weight cannot be estimated. Finally, the calculation of manipulability, resistance to wave and sinking are excluded as well.

3.2 Setting of the Design Samples

3.2.1 Yacht Samples Selecting

In this study, it was going to combine the existing
Artificial Intelligence Advances | Volume 01 | Issue 02 | October 2019

yacht's form with other features, so the eight samples, named in order from A to H, were selected as a reference based on the survey results. (See as appendix A.1) The first choice for yacht samples was that the manufacturer designed and built the length between 25 to 40 meters of yacht. For its style to reach the modern trend, the ship should be built within five years, and its main function was leisure. There was at least one closed interior space on the deck. It was mainly driven by fuel and achieving the buoyancy requirements and the regulations.

To concentrate on the exterior design, the samples presented to the participants should be displayed by outlines and feature curves, and excluded materials, color. At the same time, the influence of brand preferences on the participants was excluded as well. At the time of the investigation, the brands of the eight yachts were not disclosed: the participants only knew the length, beam and draught of the yachts.

3.2.2 Expert Survey

The study interviewed 11 yacht experts and conducted a survey of preferences, including engineers, designers and operations managers of ship researchers, shipping agents, and who were interested in yachts and had a certain level of understanding multiple yachting experience and understand the Taiwanese yacht brands, concerning about the latest yachts often.

11 experts conducted style analysis on eight ships and ranked them in order of preference. The interview results showed that the eleven experts disagreed on the style view, but only the G (Figure 3) had a similar view. In terms of the preference ranking, the number G also was scored the highest. Thus, it was going to use the number G yacht on the following study.

Figure 3. The yacht G

In addition, the interview also questioned the experts’ views on the innovative yacht styling and their acceptance of the design of the Taiwanese elements. The acceptance was also divided into 11 stages, more score more acceptance. The answers were all positive, the score statistics were shown in Figure 4. At the same time, this study provided several Taiwanese elements, namely: butterfly, Taiwanese salmon, Taiwanese leopard cat, Hakka pattern, aboriginal pattern, Taiwanese aborig-

3.3 Shape Blending and Selecting the Feature Curves

According to the results, this study selected the top two scores: Taiwanese aboriginal pattern and Taiwanese leopard cat as the Taiwanese feature elements for the new concept yacht design, respectively decomposing the feature curves, and then composing new elements and shape blending of hull.

The hull sample used the G yacht as a reference and the study selected its local feature curves. According to the side-view diagram above the waterline, the yacht curves could be divided into outlines, windows, structural lines, details, the parts of which to adjusted are selected. Then, they were blended with the same or different feature elements. The datum hull was created by DELFTship™ free, from which the outlines of the various views were obtained, and the side view and top view of the G yacht were used to obtain more detailed curves, shown as Figure 5. With the lines in the front view, top view, and right view, the curves that represent the features of the Taiwanese leopard cat could be selected. The curves of Taiwanese leopard cat's round head and strong musculoskeletal features were the final decision to join the new form of the yacht, shown as Figure 6.

Figure 4. Preference ranking and scores of the Taiwanese elements going to be blended (Score; Selection; Percentage)

DOI: https://doi.org/10.30564/aia.v1i2.1220
Figure 5. The feature curves of the G yacht

Figure 6. The selected feature curves of Taiwanese leopard cat

4. Results

The study, based on the feature parameterization method, shape morphing and other methods combining with the existing 3D CAD software DELFTship™, established a new concept yacht design process and connects them in JAVA programming language.

4.1 The Framework

After understanding the steps of the overall yacht design, the preferences of the current existing yachts from the experts and the speculations of experts on the future forming trends were obtained, as well as the features of Taiwan to be blended through the data from interviews with experts. Then the platform in JAVA could calculate the new feature curves by shape blending method, and exported the result image to DELFTship™ in order to build a 3D model and calculate the hydrostatic performance. After adjusted to a workable vessel, it was finally calculated its aesthetics values.

4.2 The Interface and Method of Shape Blending

A blending platform was written by JAVA, shown as Figure 8. After the hull and one of the sectional curves of Taiwanese leopard cat were inserted into the platform, the blending operation could be performed. The steps were as follows:

1. Inserted the point data (.txt) of the yacht and the element separately.
2. Adjusted the yacht weight $W_s$ and the element weight $W_e$, $W_s + W_e = 1$.
3. Clicked the Blending button to blend.
4. The SAVE button stored the blending result in the image file (.jpeg).
5. The Clear button cleared all point data and display curves shown on the interface.
After inserting the feature curve data, the point clouds would be converted into eigenvalues in the platform which would be normalized, and then the blending operation would be performed, converting the new eigenvalues calculated in the platform. After the data was formed, the points were connected in order by interpolation and a new feature curve was created. The result was accessed in the JPEG file.

There were four different methods for the above-mentioned blending operations: arithmetic mean method, geometric mean method, harmonic mean method and generalized weighted mean method. The four algorithms were input into the same weighting operation and compared. Because this study still emphasized on the feasibility of the hull, the blending pattern should be closer to the original one. The arithmetic mean and the geometric mean were closer to the original hull line plan. The harmonic mean showed more features of the blended element. The generalized weighted mean method had obvious differences between the original hull line plan and the characteristic elements (the four methods under the same weight value). Therefore, the arithmetic average was chosen as the calculation method of shape blending.

4.3 The Results of Shape Blending

The point clouds of the new form curves were calculated by the arithmetic mean and the new curves were calculated by interpolation in order to find the most suitable result with different weight values. The two curves of the blending process must be at the same view, such as the most upper waterline of the basic hull and Taiwanese leopard cat in the top view and the side hull outline and the side outline of Taiwanese leopard cat, as shown in the Figures 9 and 10. Some were mainly selected from yachts and blended with part of Taiwanese leopard cat curves. Figure 11 shows the outline of the fence on the deck and the curve of Taiwanese leopard cat from back to hip. Additionally, there were selecting part of two samples, namely the front end of the upper deck of the main deck and hundred pacer’s head, as shown in Figure 12.

Figure 8. The blending interface

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4.3.1 3D Forming and Hydrostatics Test

The basic model had been obtained by DELFTship™ free, and then a new feature curve was obtained by the software calculating. The original model was adjusted according to the new feature curves to obtain a new model of the yacht. Finally, it was necessary to calculate the hydrostatic performance of the new yacht. If it failed the testing, the form of the yacht had to be adjusted. It was three revises to obtain the yacht that achieved hydrostatic performance standard in the study.

4.3.2 Aesthetic Test

After the hydrostatic performance test, the 3D stereo model was output, and then returned to the JAVA platform for aesthetic testing. The new yacht model was divided into two main objects and elements. The centroid position and plane projection position were calculated respectively. It was five aesthetic factors, such as balance, unity, equilibrium, proportion and cohesion to be tested. Finally, combined the five factors to calculate the average aesthetic value (all weights were 1), and the values were all between 0 and 1. The closer to 1, the more objects met the ideal standard of aesthetics.

The final result obtained in the previous step was imported into the JAVA for aesthetic test. The following results obtained were 0.649 for balance, 0.620 for equilibrium, 0.878 for proportion, 0.770 for unity and 0.471 for cohesion, as well as 0.678 for the average (Figure 13 (a)). The result was greater than 0.5 for the aesthetic test, so in this test, the cohesion project did not achieve the standard. It was necessary to get back to the previous steps to adjust the yacht model.

After the revise, the aesthetic test results were shown in Figure 13 (b). It could be known that the cohesion value in the second result had not passed the test, so the yacht model had a fine adjustment again. The third results obtained by the test were balance 0.622, equilibrium 0.569, proportion 0.886, unity 0.770, cohesion 0.487, average 0.667 (Figure 13 (c)). Although the value of cohesion was improved, but it was still less than 0.5. However, this study focused on the accessibility of the yacht, so the step could move on to the next step if it failed over three times.
4.3.3 The Final Result

After repeatedly adjusted the yacht model through the hydrostatic performance and aesthetic test, the final result was shown in Figures 14 and 15. This new yacht was a private yacht for leisure and entertainment, suitable for families or entertaining guests. The design had a length of 33.40 m, a total length of 33.59 m, a design beam of 7.30 m, a total beam of 7.78 m, a design draft of 1.7 m, and a hydrostatic performance result of a relative water density of 1.025 and a mean shell thickness of 0.015 m. The molded volume was 122.038 m$^3$, the displacement was 127.37 tons, the longitudinal center of buoyancy is 16.301 m, the block coefficient was 0.2998, and the waterplane coefficient was 0.4932. There were two closed cabins and an open platform above the deck.

![Figure 14. The final result](image)

![Figure 15. The rendering diagram of the final result](image)

The hull is mainly blended with the Taiwanese leopard cat, showing the body curve of the Taiwanese leopard cat. The other parts that has more angular curves and the fence on the deck are also blended with the Taiwanese leopard cat's feature curves to make it more round. Also, above the main deck, a part of the yacht outline segments uses the hundred pacer’s head to blend. The hundred pacer is a respected god in the belief of the Paiwan people. It implies blessings that the hundred pacer on the deck leads the vessel going forward, wishing sailing safe. In detail, the new yacht shows the features of the aboriginal patterns, repeated and regularly arranged. Thus, a little decoration is added to enhance the image of the aboriginal patterns.

The eye of the sun is installed on the bow which follows its original meaning: the eyes of vessel. Such pattern is bound to be engraved on the canoe of the Dawu people to protect the crews from the navigation. In the results of this study also adds such elements. However, in order to make it more concise, this design slightly simplifies the original graphics, but carries the same meaning as the origin, a wish of safe sail.

5. Discussion and Conclusion

Based on the feature parameterization method, shape blending and other methods combined with the existing 3D CAD software DELFTship™ free and Rhino 5.0, this study established a new concept of yacht design process, and uses the JAVA programming language to carry out the calculation of point data.

5.1 Feature Curves and Blending Method

In this study, the feature forming is decomposed, and the feature curves are defined by the quantititative method. The necessity of the original yacht feature curves is analyzed, which can match the appropriate product image to know the understanding of the forming curve on the consumers’ perceptive, and then it is possible to select the appropriate feature curves, blended with the feature curves of other items to obtain a new feature curves. The feature data established through this mode is not only fast and objective, but accessible and possible to redevelopment in the future, which is easy to analyze in the research. The method can help the designers to develop new form, provide the designers new inspirations, and be able to mix the features curves of different things altogether at the same time. Such benefits are conducive to the development of regional style. Also, it is easy to preserve the feature data, which can be further developed and updated from this data, renewing the brand characteristics.

The platform written by JAVA program reads and blends the point data, and generates the image files that can be used for DELFTship™ free in the study. The obtained two data of point clouds are sorted out and then the remaining points are relocated and arranged in order. Finally, the two points data are integrated by ray firing method to obtain the same number of points for following calculation; in the blending process, the sorted point data is first converted into feature values and then normalized. Blending is performed on the same scale to avoid distortion due to different sizes. Calculate the new feature value, and then go backward of the previous steps to get a new feature curves.

The comparison of the results of the four formulas of
the blending method shows that the results of the arithmetic mean and the geometric mean method are similar to the original graph, and the blended curves are more predictable. The result of the harmonic mean method is significantly different from the original graph. However, it can still be seen that it is a little similar to the original, and the generalized weighted mean method has the biggest difference. Because this study focuses on the feasibility of the vessel, the arithmetic mean and geometric mean method are more suitable so this study uses the least difference method - arithmetic mean. At the same time, it can be seen that the harmonic mean method is suitable for the development of brand new product, subverting the impression of the past.

5.2 Problems and Discussions

The results of interviews with relevant industry workers and experts show that the participant's perception of each yacht is different, only a few in common. The possible reason causing the problem is that the definition of each adjective is not clearly defined, so the participants might follow their thinking based on growth background, experience and understanding of the vocabularies. These results in different imaginations, which lead to divergence of results. Therefore, it is necessary to guide the participants to understand before they fill in the questionnaire, to describe the connection between words and images, and to present photos in a monochrome stereoscopic model.

In the discussion of style and feature curves, this study only interviews workers and experts in related industries. In the future, it is better to add a large number of consumer opinions in this part, and further subdivide into statistical data of different regions, and even join the age segment for analysis. It can better reflect the market orientation, assist in the decision-making of the design, and then the accurately position in the market can capture consumer curiosity and inspire desire of purchase.

In this study, some blended feature curves are segment of the initial curves. This research method does not provide a feature curve that can be more automatically selected. In contrast, it is necessary to manually select the required curve segments. In this aspect, the computer program of the platform can add the ability about selecting partial curves, making the whole process more automatic and convenient. In addition, each software and platform are independent on each other at present. When data is processed, it is often necessary to switch between several software. If the platform for calculation can be rewritten as a plug-in for a forming software or doing operations inside the CAD software, it will be more convenient from blending to the forming process.

5.3 Conclusion

This study provides a systematic method to design the concept of yacht design: the existing yachts, with the actual animal, graphics, etc. into the yacht, constitute new curves, so that the figures can be properly combined with the existing yacht, the maximum present the special characteristics of the original graphics, and can meet the basic performance of the yacht and the legal norms. The new curve obtained from the shape blending method can also be completely preserved and provided for the next design use. The future development is to further improve the shape blending software, making the selected feature points more accurate and more representative in order to preserve the feature. Also, improving the software can decrease the time of the design process. Widely application for the brand company, it can be effectively established and save its own brand features, and further add new elements into the old product style. If a brand company wants a cross-over with different domains, this method can provide a higher level of cooperation.

Appendix

A.1 Eight Selected Yacht Samples

(a) Raised pilothouse yacht A

(b) Luxury leisure yacht B

(c) Luxury sport fisher yacht C
A.2 Taiwan’s feature pictures used in the survey

(a) Butterfly
(b) Taiwanese salmon
(c) Taiwanese Leopard cat
(d) Hakka pattern
(e) Taiwanese aborigine pattern

(d) Luxury leisure yacht D
(e) Sailing support yacht E
(f) Luxury leisure yacht F
(g) Luxury leisure yacht G
(h) Luxury leisure yacht H

References


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