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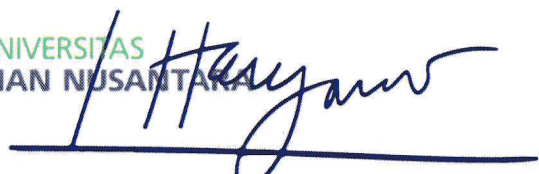
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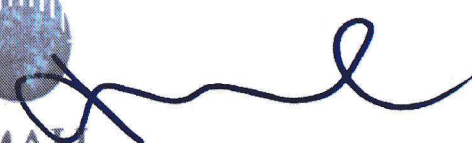
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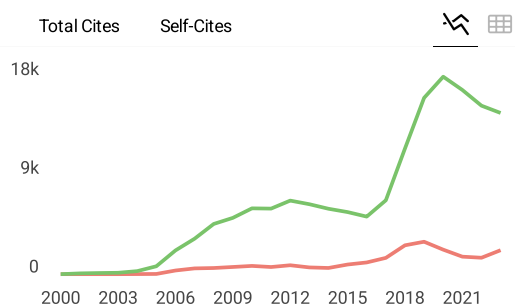
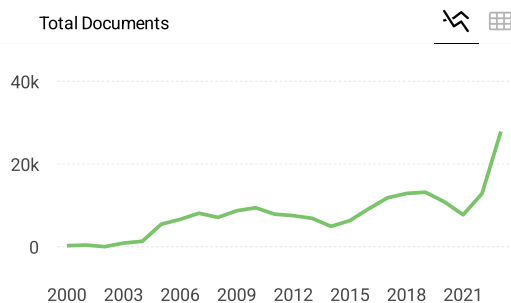
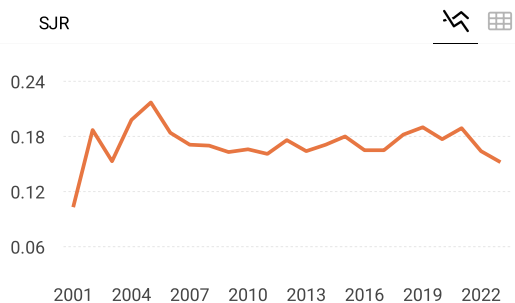
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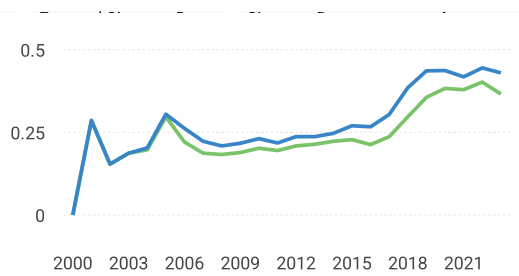
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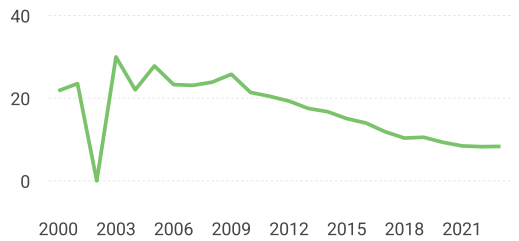
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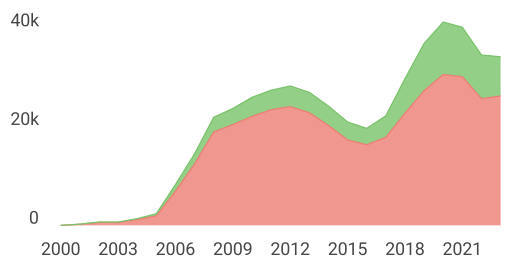




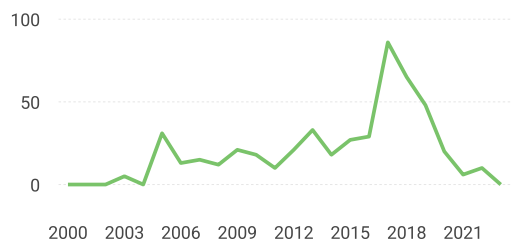
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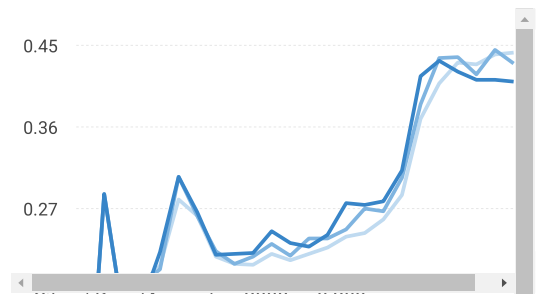
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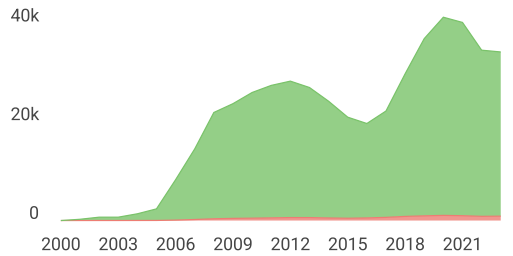
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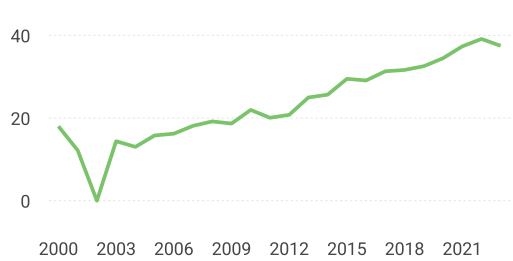
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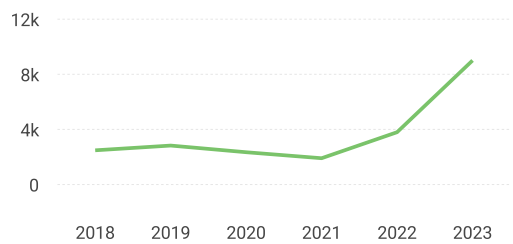
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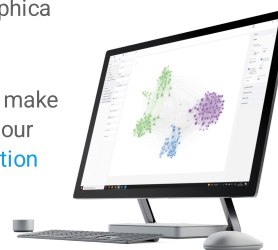


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Proceedings of the Transdisciplinary Symposium on Engineering and Technology (TSET) 2022 Development of Digital and Green Technology on Post Pandemic Era

Yogyakarta, Indonesia • 21 September 2022

**Editors • Ade Gafar Abdullah, Desi Ramayanti, Henri Septanto
and Yohanes Galih Adhiyoga**



PREFACE: Proceedings of the Transdisciplinary Symposium on Engineering and Technology (TSET) 2022

“Development of Digital and Green Technology on Post Pandemic Era”

It is with great pleasure to welcome you to Transdisciplinary Symposium on Engineering and Technology (TSET) 2022 hosted by Universitas Dian Nusantara on September 21, 2022. The event aims to a venue for engineers, researchers, scholars, and policy makers to explore the challenges and opportunities from the post pandemic era on civil engineering, mechanical engineering, electrical engineering and computer science. For civil engineers, they will play a significant part in the recovery since design and construction services will be needed in the future, and they need to develop new construction methods, materials, and technologies in order to build a sustainable and resilient infrastructure. For engineers, they need to start thinking about the long-term change of their operations and adapt to the “new normal” that has emerged because of the epidemic. We welcome all parties to share their research and thoughts in the symposium.

Participants of the symposium were invited to submit their papers and disseminate them through oral presentation covering such scope as civil engineering, mechanical engineering, electrical engineering and computer science. To enrich the discussion under the theme of “Development of Digital and Green Technology on Post Pandemic Era”, we invited speakers with reputable expertise, namely Prof. Josaphat Tetuko Sri Sumantyo, Ph.D. from Chiba University, Japan; Prof. Dr. rer. nat. Evvy Kartini, M.Sc. from National Nuclear Energy Agency of Indonesia; Prof. Dr. Ir. Bambang Sugiarto, M.Eng. from Universitas Indonesia, Indonesia; and Sulfikar Amir, Ph.D. from Nanyang Technological University, Singapore. In addition to presenting their research results, the participants of the symposium were also encouraged to submit their papers to be proposed for publication to American Institute of Physics (AIP), one of the world’s top publishers as conference proceedings. There were 125 manuscripts submitted to the committee comprising 99 papers of Biology, Chemistry, Computer Science and Technology, and Engineering.

Finally, on behalf of the editors of TSET 2022, I would like to extend my most sincere gratitude to the organizing committee, co-hosting institutions, and most importantly, participants, speakers, presenters, and authors of the symposium. I do hope the proceedings bring significant contribution, particularly to the field of advances of sustainable engineering. I look forward to seeing you all at the upcoming symposium.

The Editors,
Ade Gafar Abdullah
Desi Ramayanti
Henri Septanto
Yohanes Galih Adhiyoga

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Synthesis and characterization of SnO₂ nanoparticles using electrolysis methods 𐄂

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Preparation of nickel hydroxide nanoparticles with the electrolysis method 𐄂

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Flood area mapping and flood hazard assessment in Utama Urban village, South Cimahi 🛒

[Iin Karnisah](#); [Enung Enung](#); [Moch. Yusup](#); [Beny Mulyana Sukandar](#); [Yackob Astor](#); [Idmoneia Bianca Nugraha](#); [Tety Tamariska Oktiara Bangun](#); [Frenki Tres Widiantoro](#)

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Flood vulnerability mapping in Cimahi city, Indonesia

[Iin Karnisah](#); [Enung Enung](#); [M. Yusup](#); [Beny Mulyana Sukandar](#); [Yackob Astor](#); [Ainnaya Sajida](#); [Hana Fitri Khairani](#)

AIP Conf. Proc. 3077, 050018 (2024) <https://doi.org/10.1063/5.0201091>

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Guitar chord recognition using MFCC based feature extraction with Kaiser windowing

[Linggo Sumarno](#)

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The fit and predict COVID-19 using an extended compartmental model in the context of Indonesia

[Indrazno Siradjuddin](#); [Bella Cahya Ningrum](#); [Inta Nurkhaliza Agiska](#); [Arwin Datumaya Wahyudi Sumari](#); [Yan Watequlis Syaifudin](#); [Rosa Andrie Asmara](#); [Nobuo Funabiki](#)

AIP Conf. Proc. 3077, 050020 (2024) <https://doi.org/10.1063/5.0201201>

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Optimizing the implementation of the XXX mall project with the integration of the earned value and time cost trade off methods

[Rifaldi Adi Saputra](#); [Era Agita Kabdiyono](#)

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Pavement conditions evaluation based on guidelines for pavement condition index (PCI) with the assistance of unmanned aerial vehicle (UAV)

[Retno Utami](#); [Iman Ruchiat](#); [Yackob Astor](#); [Atmy Verani Rouly Sihombing](#); [R. Desutama Rachmat Bugi Prayogo](#); [Dewi Amalia Pertiwi](#); [Reggina Mulya Sari](#)

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Road performance assessment after the existence fly over on roads in Indonesia

[Alman Rahadiansyah Willianto](#); [Muhammad Raihan Nugraha](#); [Yackob Astor](#); [Asep Sundara](#)

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Planning of bicycle lane as sustainable transportation to support post pandemic adaptation in Cimahi city, Indonesia

[Agah Muhammad Mulyadi](#); [Anisa Mardiyanti Putri](#); [Sally Nuraeni](#); [Fairuz Albi Asyhari](#); [Aldo Organami](#); [Hanafi Hanafi](#)

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Reverse engineering of steam turbines for national manufacturing industry independence

[D. Febriansyah](#); [R. Harmadi](#); [K. Herbandono](#); [Faisal Faisal](#); [C. S. A. Nandar](#)

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SCADA application for popcorn cooking and packaging system using PLC and internet

[Theresia Prima Ari Setiyani](#); [Geraldine Valda Prakusya Putri Ayu](#); [Ignatia Diva Saniscara](#)

AIP Conf. Proc. 3077, 050026 (2024) <https://doi.org/10.1063/5.0201806>

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Analysis bending capacity of camphor wood-concrete composite beams with carbon fiber reinforced polymer

[Pamella Meidina Sri Rezeki](#); [Mujiman Mujiman](#)

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The effect of adding marble dust on compressive strength and bearing capacity value for soft clay soil 

[Syahril Syahril](#); [Agus Suyono](#); [Hendry Hendry](#); [Muchtar Muchtar](#); [Muhammad Raihan Riandi](#)

AIP Conf. Proc. 3077, 050028 (2024) <https://doi.org/10.1063/5.0201795>

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The effect of atmospheric temperature on brine cooling performance using nylon tube on liquid line and suction line 

[Arda Rahardja Lukitobudi](#); [Sugiyarto](#); [A. P. Edi Sukamto](#); [Triaji Pangripto Pramudantoro](#); [Cindy Gamas](#); [Verino Apriliano Prio Utomo](#)

AIP Conf. Proc. 3077, 050029 (2024) <https://doi.org/10.1063/5.0207227>

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The effect of austenization temperature variations on the mechanical properties of stainless steel 

[Janatika Putra Perdana](#); [Margono Sugeng](#)

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The effect of rice husk ash and phosphoric acid as soft soil stabilizing agent for plasticity index value 

[Muhammad Raihan Riandi](#); [S. Syahril](#)

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The effect of squeezing force to the shear strength of sengon wood and coconut wood using Poly Vinyl Acetate adhesive 

[Muhammad Taufan](#); [Mujiman Mujiman](#); [Yulianto Petrus Krisologus](#)

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The implementation of MPPT incremental conductance method with boost converter on PV system

[Dorothy Patricia Monique](#); [Yehezkiel Krisma](#); [Petrus Setyo Prabowo](#); [Bernadeta Wuri Harini](#)

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The implementation of MPPT Perturb and observe method with boost converter on PV system

[Agnesia Felita](#); [Yehezkiel Krisma](#); [Petrus Setyo Prabowo](#); [Bernadeta Wuri Harini](#)

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Utilization of unmanned aerial vehicle for pavement condition evaluation with surface distress index method on the Bandung-Subang road, Indonesia

[Yackob Astor](#); [Retno Utami](#); [Atmy Verani Rouly Sihombing](#); [Rd. Bugi Prayogo Desutama](#); [Saldila Pramestu](#); [Syahreza Apriansyah](#)

AIP Conf. Proc. 3077, 050035 (2024) <https://doi.org/10.1063/5.0201319>

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Integrated tourism village system (IToViS) development for tourism village

[Ni Luh Ayu Kartika Yuniastari Sarja](#); [Made Riyan Adi Nugroho](#); [I. Gde Agus Jaya Sadguna](#); [I. Nyoman Meirejeki](#); [Kadek Nita Sumiari](#); [Ni Ketut Pradani Gayatri Sarja](#)

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Quality improvement of fungicide products packaging using FMEA and continuous improvement 🛒

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Determining preventive maintenance interval to increase the reliability of air turbine engine starter 🛒

[Ellysa Nursanti](#); [Sibut Sibut](#); [Sunarjono Prijohutomo](#)

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Land management in fisherman's settlement as slum control, in Tanah Laut Regency, South Kalimantan 🛒

[Ghestiar Kharisma Kusumo](#); [Agung Witjaksono](#); [Maria C. Endarwati](#)

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Optimal integration of wind turbine into the grid with artificial intelligence-based microgrid controller 🛒

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Energy absorption and deformation pattern of honeycomb hybrid crash box under frontal load 🛒

[Fina Andika Frida Astuti](#); [Moch. Agus Choiron](#); [Anindito Purnowidodo](#); [Yudy Surya Irawan](#)

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Landslide mitigation through NDSI-based soil erodibility value prediction on coffee land in Wajak subdistrict, Malang Regency, East Java 🛒

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A medicine and food delivery robot for Covid-19 hospital using Labview MyRIO FPGA 🛒

Irmalia Suryani Faradisa; Agung Darmawan; Yudi Limpraptono; Abraham Lomi

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Design of solar panel for electric car power supply with four selenoid in-line engine 🛒

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Spare parts inventory control to minimize total inventory cost using continuous review system and periodic review system approaches 🛒

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Real-time structural health monitoring (SHM) using strain gauge Arduino sensor at reinforcement concrete under static and impact loading 🛒

Vega Aditama; Sri Murni Dewi; Ari Wibowo; Ming Narto Wijaya

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Treatment performance of Tlogomas communal wastewater treatment plant

[Evy Hendriarianti](#); [Candra Dwiratna Wulandari](#); [Andika Yoga Pradana](#); [Suhaena Wisma Ernia Sindy](#)

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Crack pattern in concrete beam continuous shear reinforcement with numerical method

[Mohammad Erfan](#); [Yosimson P. Manaha](#); [W. S. Hadi Surya](#); [Vega Aditama](#)

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Evaluating energy efficiency and conservation, water conservation, indoor health and comfort on conservation building

[Aurelius Andri Wibowo](#); [Maranatha Wijayaningtyas](#); [Lalu Mulyadi](#)

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Analysis of appropriate site development on public building with greenship criteria green building

[Lea Mahdarina](#); [Maranatha Wijayaningtyas](#); [Lila Ayu Ratna Winanda](#); [Deviany Kartika](#)

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Low-cost high-performance MEMS inertia measurement unit (IMU) for seismic activity monitoring

[Bima R. P. D. Palevi](#); [Djoko H. Praswanto](#); [Ratri Andinisari](#); [Citra D. Megawati](#); [Rachmadi Setiawan](#)

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Participatory ergonomics-based work productivity strategy for Wijaya Kusuma bakery's home industry

[P. Vitasari](#); [Julian Candra Purnama](#); [Sony Harianto](#); [Fuad Achmadi](#); [Suriya Kumar Sinnadurai](#)

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The use of smart contracts for third-party comparison web logistics

[Nataniel Albert Angstein](#); [Joniarto Parung](#)

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Implementation of a low-cost embedded multi-camera system for leaf plant monitoring in the greenhouse

[Aryuanto Soetedjo](#); [Evy Hendriarianti](#); [Muhammad Suriansyah](#); [M. Rifki Abdilah](#); [M. Syahriel](#); [H. M. Mohamad Khafil](#)

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Voltage stability analysis using probability density function with real load on Karangploso's Feeder Singosari distribution system

[Irrine Budi Sulistiawati](#); [Ahmad Iqbal Zajuli](#); [Sugeng Priyanto](#); [Awan Uji Krismanto](#); [Adlan Bagus Pradana](#); [Aji Akbar Firdaus](#)

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Rural thematic map based on a strategical issue approach

[Muhammad Nelza Mulki Iqbal](#); [Antonio Heltra Pradana](#); [Debby Budi Susanti](#)

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The first order Fischer-Tropsch reaction rate constant calculation from carbon monoxide based conversion data



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Geometric quality of orthophoto from aerial images obtained by UAV's consumer grade camera: Lesson learnt 🛒

Silvester Sari Sai; Martinus Edwin Tjahjadi; Masrurotul Ajiza; Hery Purwanto

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Effect of the variation of composted solid waste treatment on the addition of bioactivators at Loka Bhakti 3R solid waste treatment facility, Pakisaji Malang, Indonesia 🛒

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Preliminary assessment on the performance of long distance wireless data transmission for disaster early warning system

[Michael Ardita](#); [Alfarid Hendro Yuwono](#); [Gatot Kusrahardjo](#); [Radimas P. M. D. Labib](#); [Kartiko Ardi Widodo](#)

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Experimental study a low speed-one phase generator with permanent magnetic radial flux

[Syafriyudin Syafriyudin](#); [Muhammad Suyanto](#); [Aji Pranoto](#)

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Design and analysis of cabin carbon monoxide warning system

[Erfan Rohadi](#); [Rudy Ariyanto](#); [Indrazno Siradjuddin](#); [Kristinanti Charisma](#)

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A Modified Iterative Method for Solving the Hamilton-Jacobi-Bellman Equation

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Abstract. In the field of optimal control, the Hamilton-Jacobi-Bellman equation specifies both the necessary and sufficient condition for finding optimal control with respect to the intended objective function. The equation is a nonlinear partial differential equation which is generally intractable to be solved analytically. Hence, in order to obtain the solution of some optimal control problem formulated in the Hamilton-Jacobi-Bellman equation, it is necessary to develop some reliable and efficient numerical method. In this article, we propose a modified version of our iterative method, previously published in a journal, to solve the state-constrained Hamilton-Jacobi-Bellman equation. The modification is made on the way to update the value function of the objective function. In this new scheme, instead of updating the value function on each point on the domain, we select only some points neighboring a nominee of the optimal path making up the solution of the optimal control problem. Therefore, comparing to the old scheme, the computation results not only a reliable solution but it is also much faster and efficient.

INTRODUCTION

Optimal control is a field of Mathematics and Engineering that aims to find an optimal way to control a dynamical system. This kind of problem naturally occurs in decision making of many aspects such as science, engineering [1], finance and management [2,3,4] and even medical sciences [5,6,7,8]. Basically, to solve an optimal control problem we need to optimize some objective function under constraints of a differential equation system. In the literature, there are two ways to solve an optimal control problem. We can use a method of Pontryagin Minimum Principle or Bellman Dynamic Programming. The former method results in an open loop problem whose solution is easier to find and constitutes an optimal control along the optimal trajectory from the initial state. Unfortunately, this solution is not robust. If for some reason the state is off the optimal trajectory then the corresponding optimal control is no longer valid. On the other hand, using Bellman Dynamic Programming the optimal control problem will be formulated in Hamilton-Jacobi-Bellman equation [9,10,11,12,13].

In this article we will solve an optimal control problem with a state-constraint in the form of

$$\begin{aligned} \min_{u \in \Omega} J(u) &= \int_0^1 L(x, u, t) dt + \Phi(x(1)) \\ \frac{dx}{dt} &= f(x, u, t), \quad t \in (0,1), \quad x(0) = z \\ \Omega &= \{u | h(x, u, t) \leq 0\}, \quad t \in (0,1] \end{aligned} \tag{1}$$

The corresponding Hamilton-Jacobi-Bellman equation of this unconstrained problem is the following.

$$\begin{aligned} \frac{\partial V}{\partial t} + \min_u (\nabla V \bullet f(x, u, t) + L(x, u, t) + \lambda h(x, u, t)) &= 0 \\ V(1, x) &= \Phi(x(1)) \end{aligned} \quad (2)$$

The solution of Hamilton-Jacobi-Bellman equation is a robust solution because it is defined over a time-space region that the optimal trajectory lays. Hence, the corresponding optimal control still can be traced if the state is off the optimal path. However, the Hamilton-Jacobi-Bellman equation is generally unsolvable analytically. Therefore, we should solve it numerically. There are some methods for solving it such as in [9,10] and [14] to name but a few. However, most of them are devoted to solve general Hamilton-Jacobi-Bellman equation without constraint on control and state. Our proposed numerical method is unique because it aims to solve constrained Hamilton-Jacobi-Bellman equation using a penalty method.

MODIFIED ITERATIVE METHOD

This modified iterative method is a modification of method in the article [15]. The old method uses an iterative finite upwind difference method to evaluate the value function on all grid points in the time and space domain. The method we present here evaluate the value function on selected grid points in time and space domain without sacrificing accuracy of the computation. As a consequence, our new method will be faster and more efficient in terms of computational time. In the following part, we describe the method in detail and give a numerical simulation to show the effectiveness of the method.

First Iteration

Without loss of generalization, let us simplify the notation by taking an optimal control problem with 1 control variable u and 2 state variables $x_p \in [a_p, b_p]$, $p = 1, 2$. First, we will discretize space and time interval into m and n partitions respectively. Therefore, we have

$$\Delta x_p = \frac{b_p - a_p}{m}, \quad x_{p,i} = a_p + (i-1) \Delta x_p, \quad p = 1, 2, \quad i = 1, 2, \dots, m+1 \quad (3)$$

An appropriate shifting may need to be done such that this spatial discretization in any case contains the initial point. In this scheme, in order to work well the upwind finite difference method that we use need a stability condition as reported in [15], i.e.

$$n \geq \sum_{p=1}^2 \frac{\|f_p\|_{\infty}}{\Delta x_p} \quad (4)$$

Hence,

$$\Delta t = -\frac{1}{n}, \quad t_k = 1 + (k-1) \Delta t, \quad k = 1, 2, \dots, n \quad (5)$$

is the backward partition of time interval $[0,1]$. We set the initial value function and control value as follows.

$$V_{i,j}^1 = \Phi(\vec{x}_{i,j}(1)), \quad i, j = 1, 2, \dots, m+1 \quad (6)$$

$$\begin{aligned} u_{i,j}^1 &= \arg \min_u (f_1(t_1, \vec{x}_{i,j}, u) \frac{V_{i,j}^1 - V_{i-1,j}^1}{\Delta x_1} + f_2(t_1, \vec{x}_{i,j}, u) \frac{V_{i,j}^1 - V_{i,j-1}^1}{\Delta x_2} + L(t_1, \vec{x}_{i,j}, u) \\ &\quad + \lambda h_{\varepsilon}(t_1, \vec{x}_{i,j}, u), \quad i, j = 2, 3, \dots, m+1. \end{aligned} \quad (7)$$

In the above formulas, $V_{i,j}^k \approx V(t_k, \vec{x}_{i,j})$ and $u_{i,j}^k \approx u(t_k, \vec{x}_{i,j})$ are value function and control variable at point $\vec{x}_{i,j} = (x_{1,i}, x_{2,j})$ and time t_k . The function $h_{\varepsilon}(t_1, \vec{x}_{i,j}, u)$ is smoothed form of constrain $h(t, x, u)$ evaluated at $(t_1, \vec{x}_{i,j}, u)$ as in [15] and λ is a constant of explicit penalty term used to embed constraint to the objective function.

To prevent a trapezoidal propagation on the boundary of space domain for each time step, we add some artificial boundary conditions for control function. This boundary values are predicted using a linear extrapolation of the closest known points.

To update value function for $i, j = 1, 2, \dots, m+1, \quad k = 1, 2, \dots, n$

$$\begin{aligned} V_{i,j}^{k+1} = & -\frac{1 + \text{sign } f_1}{2} \beta_1 f_1(t_k, \vec{x}_{i,j}, u_{i,j}^k) V_{i+1,j}^k - \frac{1 + \text{sign } f_2}{2} \beta_2 f_2(t_k, \vec{x}_{i,j}, u_{i,j}^k) V_{i,j+1}^k \\ & + \frac{1 - \text{sign } f_1}{2} \beta_1 f_1(t_k, \vec{x}_{i,j}, u_{i,j}^k) V_{i-1,j}^k + \frac{1 - \text{sign } f_2}{2} \beta_2 f_2(t_k, \vec{x}_{i,j}, u_{i,j}^k) V_{i,j-1}^k \\ & + (1 + \sum_{p=1}^2 \beta_p |f_p(t_k, \vec{x}_{i,j}, u_{i,j}^k)|) V_{i,j}^k - \Delta t L(t_k, \vec{x}_{i,j}, u_{i,j}^k) - \Delta t \lambda h_\varepsilon(t_k, \vec{x}_{i,j}, u_{i,j}^k) \end{aligned} \quad (8)$$

where $\text{sign } f_p$ denotes the sign of $f_p(t_k, \vec{x}_{i,j}, u_{i,j}^k)$ and $\beta_p = \frac{\Delta t}{\Delta x_p}$, $p = 1, 2$. For both ends of spatial domain, the value functions at those points are extrapolated using linear method similar to the (9).

In addition, control values for $i, j = 2, 3, \dots, m+1, \quad k = 1, 2, \dots, n$ are given as the following

$$\begin{aligned} u_{i,j}^{k+1} = \arg \min_u & (f_1(t_{k+1}, \vec{x}_{i,j}, u) \frac{V_{i,j}^{k+1} - V_{i-1,j}^{k+1}}{\Delta x_1} + f_2(t_{k+1}, \vec{x}_{i,j}, u) \frac{V_{i,j}^{k+1} - V_{i,j-1}^{k+1}}{\Delta x_2} \\ & + L(t_{k+1}, \vec{x}_{i,j}, u) + \lambda h_\varepsilon(t_{k+1}, \vec{x}_{i,j}, u). \end{aligned} \quad (9)$$

For left and right boundaries for control value, we do a linear extrapolation as before.

Up to this point, we already have $V_{i,j}^k$ and $u_{i,j}^k$ for $i, j = 1, 2, \dots, m+1, \quad k = 1, 2, \dots, n+1$. To find the optimal trajectory and control, we need to integrate forward the state equation from the starting point

$$\frac{d\vec{x}}{dt} = \vec{f}(t, \vec{x}, u), \quad \vec{x} = (x_1, x_2), \quad \vec{f} = (f_1, f_2) \quad (10)$$

using predictor-corrector method as follows. Let us label the resultant path and control for predictor $\vec{y}_q = (y_{q,1}, y_{q,2})$, u_q and $\vec{y}_c = (y_{c,1}, y_{c,2})$, u_c for corrector with $\vec{y}_q(1) = \vec{y}_c(1) = \vec{x}_0$ and $u_c(1) = u(\vec{x}_0, t_{n+1})$ respectively. The control value used during the integration is the optimal control value from the closest grid point to the resultant state. Then, for $l = 2, \dots, n+1$

$$\begin{aligned} \vec{y}_q(l) &= \vec{y}_c(l-1) - \Delta t \vec{f}(t_{-l+n+3}, \vec{y}_q(l), u_c(l-1)) \\ u_q(l) &= u(\vec{x}_{i^*,j^*}(l), t_{-l+n+3}), \quad (i^*, j^*) = \arg \min_{(i,j)} \|\vec{y}_q(l) - \vec{x}_{i,j}\| \\ \vec{y}_c(l) &= \vec{y}_c(l-1) - 0.5 \Delta t (\vec{f}(t_{-l+n+3}, \vec{y}_c(l-1), u_c(l-1)) + \vec{f}(t_{-l+n+3}, \vec{y}_q(l), u_q(l))) \\ u_c(l) &= u(\vec{x}_{i^*,j^*}(l), t_{-l+n+3}), \quad (i^*, j^*) = \arg \min_{(i,j)} \|\vec{y}_c(l) - \vec{x}_{i,j}\| \end{aligned} \quad (11)$$

The resultant pair $(\vec{y}_c(l), u_c(l))$, $l = 1, 2, \dots, n+1$ constitutes an optimal trajectory and control for all time stages. Moreover, the value function along the optimal trajectory can be obtained using the value function of the corresponding closest grid points. Similarly, the penalty value and objective function value can be determined by forward integration along the optimal trajectory of corresponding terms.

Second Iteration

Next, for the second iteration we firstly reduce the domain based on the optimal trajectory and control found in the first iteration. This reduction will save a lot of computational time and is done as following. First, we determine the maximum and the minimum value of resultant path and control. For $p = 1, 2$ and $l = 1, 2, \dots, n + 1$

$$\begin{aligned} x_{p,max} &= \max_l y_{c,p}(l), x_{p,min} = \min_l y_{c,p}(l) \\ u_{max} &= \max_l u_c(l), u_{min} = \min_l u_c(l) \end{aligned} \quad (12)$$

For this iteration we double the number interval partitions m and set the region as follows.

$$\begin{aligned} m_{new} &= 2m, \quad \Delta x_{p,new} = \frac{x_{p,max} - x_{p,min}}{m_{new}}, \quad a_{p,new} = x_{p,min} - d \Delta x_{p,new} \\ b_{p,new} &= x_{p,max} + d \Delta x_{p,new}, \quad u_{low} = \lfloor u_{min} \rfloor, \quad u_{up} = \lceil u_{max} \rceil \end{aligned} \quad (13)$$

where $\lfloor z \rfloor$ floor function, $\lceil z \rceil$ ceiling function and d some given constant. This constant d is a prescribed distance for selected grid points from the optimal trajectory. The shrinkage factor ρ_p can be evaluated using the following formula.

$$\rho_p = \frac{b_{p,new} - a_{p,new}}{b_p - a_p}, \quad p = 1, 2. \quad (14)$$

This shrinkage factor will be used to update distance d .

Then, we determine the number of time stages as previously explained in (4) and discretize the spatial domain as in (3). Shifting the spatial discretization to include the initial value can be done if needed. We select some grid points among the existing ones in the space domain based on the distance from the optimal trajectory resulted from the first iteration. In principle, we choose points $\vec{x}^d$ closed to the optimal trajectory $\vec{y}_c$ within some given distance d .

$$\|\vec{y}_c - \vec{x}^d\|_1 < d \quad (15)$$

Afterwards, we set the value function and control for these selected grid points. There are two kinds of grid points that need to be considered, i.e. interior and border points. Interior points are points that are surrounded by other selected points and therefore their initial value function is determined following (10). For border points, points that are directly adjacent to unselected points, at position (i, j) and time $k = 1$ the value function will be extrapolated from the known value function of the interior points. This value functions always exists due to the compactness of points close to the optimal trajectory for some (big enough) given distance d .

Analogously, the initial control for interior points is determined using formula in (7) and for border points at position (i, j) and time $k = 1$ we do a linear extrapolation as before. The value function at next time stages follows from (8) for interior points and is extrapolated for border points. Similarly, control for later time stages can be updated using (9) for interior points and is extrapolated for border points. So far, we have $V_{i,j}^k$ and $u_{i,j}^k$ for $i, j = 1, 2, \dots, m + 1$, $k = 1, 2, \dots, n + 1$, and therefore we have already updated all values. Next, we integrate forward the dynamical system to obtain optimal pair $(\vec{y}_c, u_c)$ for all time stages using predictor-corrector method as before. If during the integration, the resultant trajectory is off the selected grid points, we enlarge the distance d by one grid spacing and start again the integration with this new distance.

Like in the first iteration, next, we need to reduce the region size. To include these selected points for the next iteration the distance is updated as follows.

$$\gamma = \max\left(\frac{1}{\rho_1}, \frac{1}{\rho_2}\right), \quad d_{new} = 2 \gamma d. \quad (16)$$

where $\rho_p, p = 1, 2$ is the shrinkage factor of space interval between two consecutive iterations.

Next Iteration

Repeat all steps in the second iteration for later iterations. We stop the iteration if maximum iteration is reached or the difference between two consecutive value function at the initial state point are less than some prescribed tolerance.

NUMERICAL SIMULATION

In this section we will run a numerical simulation to show the effectiveness of the proposed method. The example taken from [15] is as follows.

$$\begin{aligned} \min_u J(u) &= \int_0^1 (x_1^2 + x_2^2 + 0.005 u^2) \\ \frac{dx_1}{dt} &= x_2, \quad x_1(0) = 0 \\ \frac{dx_2}{dt} &= -x_2 + u, \quad x_2(0) = -1 \\ g(t, x) &= -8(t - 0.5)^2 + 0.5 + x_2 \leq 0, \quad t \in [0, 1] \end{aligned} \quad (17)$$

The last constraint constitutes a purely state constraint so that it does not give any information on how to choose a control that satisfies it. Therefore, it should be changed to a new constraint according to as following.

$$h(t, u, x) = 0.9 g(t, x) + 0.1 \frac{dg(t, x)}{dt} \quad (18)$$

Furthermore, in order to be able to work with optimization routine this constraint need to be smoothed as follows.

$$h_\varepsilon = \begin{cases} 0, & h < -\varepsilon \\ \frac{1}{4} \frac{(h+\varepsilon)^2}{\varepsilon}, & -\varepsilon \leq h \leq \varepsilon \\ h, & h > \varepsilon \end{cases} \quad (19)$$

The above optimal control problem can be converted into Hamilton-Jacobi-Bellman (HJB) equation

$$\begin{aligned} \frac{\partial V}{\partial t} + \min_u (x_2 \frac{\partial V}{\partial x_1} + (u - x_2) \frac{\partial V}{\partial x_2} + x_1^2 + x_2^2 + 0.05 u^2 + \lambda h_\varepsilon(t, x, u)) &= 0 \\ V(1, x) &= 0 \end{aligned} \quad (20)$$

In this numerical simulation we set $\lambda = 2$, $\varepsilon = 10^{-2}$ and at the first iteration, we choose the region $-1 \leq x_1 \leq 1$, $-3 \leq x_2 \leq 1$, $-20 \leq u \leq 20$, $m = 8$. For various values of m the result of the computational results are displayed in Table 1 and Table 2.

TABLE 1. Computational value function

Iterations	Distance d	m	n	Penalty	Objective function	Value function	Control range
1	-	8	46	0.204	0.1763	0.4378	[-20,20]
2	2.00	16	164	0.020	0.2016	0.2186	[-6,14]
3	4.65	32	331	0.024	0.1921	0.2141	[-3,14]
4	9.26	64	658	0.003	0.2044	0.2099	[-3,14]
5	19.13	128	1331	0.003	0.2025	0.2078	[-3,14]

Columns in Table 1 shows us respectively the number iterations, distance, the number of partitions for space and time domain, penalty and objective value along the optimal path, value function at the initial point and control range that we used. We see that from iteration to iteration penalty value and value function decreases as expected. Meanwhile, the value function increases and the discrepancy between the value function and the objective function is getting smaller.

TABLE 2. Computational shrinkage factors

Iterations	Distance d	m	n	x1 range	x2 range	ρ_1	ρ_2	% m
1	-	8	46	[-1, 1]	[-3,1]	0.14	0.44	-
2	2.00	16	164	[-0.243, 0.034]	[-1.217,0.523]	1.24	0.86	60
3	4.65	32	331	[-0.310,0.034]	[-1.217,0.281]	1.06	1	65
4	9.26	64	658	[-0.316,0.050]	[-0.217,0.286]	1.06	0.97	63
5	19.13	128	1331	[-0.334,0.053]	[-0.217,0.238]	1.02	1	63

Table 2 provides some information related to the range of spatial domain and the shrinkage factor, i.e. the ratio of latter space interval length to former. The smaller the shrinkage factor is, the larger the reduction for the next iteration. The shrinkage factor nearly 1 indicates that the length of the space interval for the next iteration will not change much. Moreover, if the control range is fixed, this also means that the iteration is almost convergent and further improvement will be impossible. On the contrary, the shrinkage factor exceeding 1 indicates that the previous interval length is too short so that the method automatically adapts it to restore. The last column informs us the percentage of grid point evaluation compared to method without grid selection. It can be seen that for this simulation the method only evaluate not more than 65% of the complete set of grid points. Consequently, the efficiency of computational time can be increased about 35% and the best value function found is just insignificantly different from the result reported in.

The following figures shows the comparison between the optimal path generated by two consecutive iterations and MISER 3.3, a reliable software for solving optimal control problem in [16].

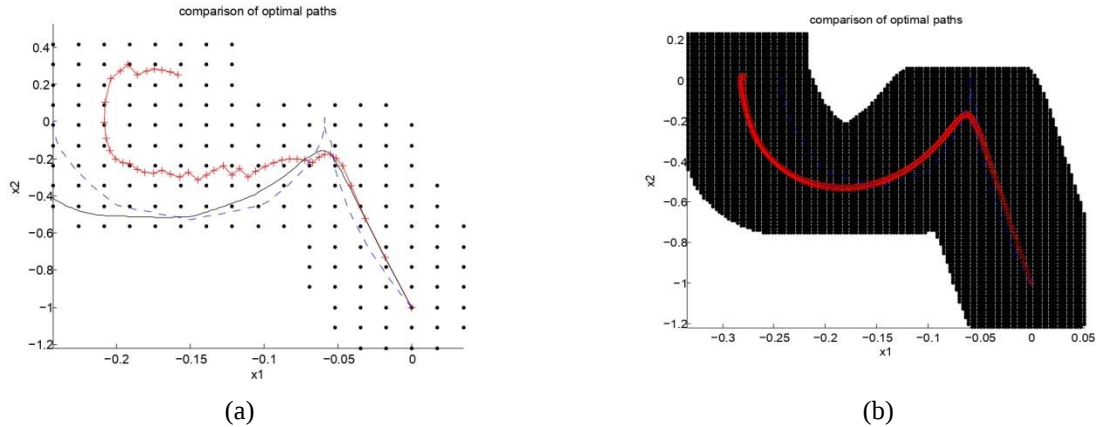


FIGURE 1. Optimal path comparison of two consecutive iterations, i.e. iteration 2 in (a) and last iteration in (b)

Figure 1(a) shows optimal paths produced by first iteration (-+), second iteration (-) and MISER 3.3 (- -). It is noted that the optimal paths from the first two iterations and MISER 3.3 are different. However, in the last iteration in figure 1(b) this discrepancy disappears and the optimal finally coincide. This indicates that from time to time the method could improve the computation such that the optimal paths produced converge to the true solution.

Figures 2 below show the computational result from the last iteration for value function at initial time ($t=0$) in (a) and at the final time ($t=1$) in (b). The similar basic S-shape in the figures indicate that the method is quite stable under proposed distance d.

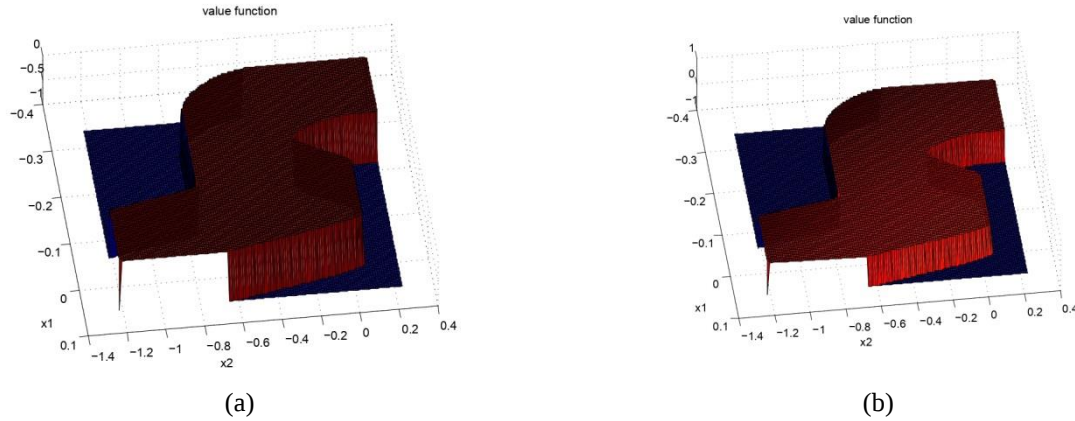


FIGURE 2. The value function in the last iteration at initial time ($t=0$) in (a) and final time ($t=1$) in (b)

CONCLUSION

In this article, we modify the method of iterative upwind finite difference method in order to improve the speed of computation. From the numerical simulation the new proposed method is much more efficient than the previous one. This is due to the selection of grid points evaluated in each iteration. Furthermore, in higher dimensions using the proposed method the computation could be even more efficient. However, it is necessary to investigate the minimal value of distance d further because choosing d too small will likely result in instability of the scheme.

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