

Short thesis for the degree of doctor of philosophy (PhD)

**NUMERICAL AND ANALYTICAL COMPARISON OF BOND
GRAPH IN MECHATRONICS ENGINEERING EDUCATION**

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Dissertation Booklet

1 State of the Art for the test

Mechatronics has become an essential subject in multi-domain engineering because of its interdisciplinary characteristic [1]. Mechatronics is a combined word created by a Japanese engineer in the 60s 20th century [2]. It is well-accepted that mechatronics is an interdisciplinary subject because it contains multiple fields such as mechanical, electronics, and control theory. In the meantime, mechatronics education has become a critical subject because of the multiple domains. This dissertation proposes the Bond Graph as a novel teaching method to help mechatronics engineering students and researchers in many fields, such as dynamic modeling systems, representation of the controllers, and the Lagrangian mechanism system.

1.1 Mechatronics Education

Mechatronics can be concluded as an application of complex operations in a dynamic system [3]. Mechatronics is not a simple combination of mechanical and electronics, but a system of control integration [4]. These definitions and introductions of mechatronics are well-stated and accurate, but not detailed enough to describe the whole capture of mechatronics.

The teaching method of the mechatronics subject is based on the experiences of the lecturers [5], which makes a synergy tool necessary to combine the multiple fields. The theoretical part of mechatronics is a youthful subject [6] with the understanding from engineers from the mechatronics characteristics and philosophy. From a practical mechatronics point of view, it takes a long period for mechatronics students to digest the multiple domains of knowledge [7]. It becomes a remaining task to be solved over decades, this dissertation proposes the Bond Graph as a handy teaching tool to integrate multiple fields to accelerate the learning curve of mechatronics students.

1.2 Bond Graph and Traditional Method

The Bond Graph is a graphical language to illustrate the process between the 'modeling and the simulation'. The Bond Graph gives a concise description of a complex system in the form of a vector, which greatly improves people's insight into the behavior of engineering systems [8]. At present, the Bond Graph has been widely used in the dynamic analysis and control research of mechanical, electronic, and magnetic systems and other mechatronics engineering fields [9]. Especially in recent years, its applications have been extended to agricultural, solar, and nuclear energy systems [10]. Because of the multiple domain applications, it is logical to introduce the Bond Graph as a novel teaching method in mechatronics education.

The Bond Graph method provides great convenience for researchers to analyze the dynamic characteristics of the system and establish mathematical models [11]. On the one hand, there is a clear physical correspondence between each structure in the Bond Graph and the dynamic factors of the system [12]; On the other hand, The Bond Graph provides a very effective way to accurately define and describe the dynamic model of a system and derive the state equations accordingly [13].

Existing system dynamics analysis methods, often limited to a single energy domain of the system [14][15], for a variety of energy forms integrated engineering systems, the Bond Graph provides a unified way to automatically realize the system dynamics modeling and simulation on the computer with effective global dynamic performance analysis.

The Bond Graph theory based on the principle of energy conservation can deal with the modeling and simulation problems of multiple energy forms in a unified way, which has the features of simple structure, large amount of information, and regularization of the dynamics modeling process [16].

For the multiple domains analysis, the traditional method requires dynamic system analysis [17][18]. Compared with the traditional method, the Bond Graph presents a solution to get a simulation result with complex mathematics analysis. In

the meantime, the Bond Graph has synergy characteristics by modeling the multiple domains using one graph. Compared with the traditional mathematical solution, the Bond Graph provides a graphical practical tool to solve the modeling and simulation.

The Bond Graph theory has the following significant features compared with other dynamical methods summarized in the following:

- A unified approach of multiple energy domains of the system;
- Reveal the dynamics of the system intuitively in a concise graphical way;
- The system equations of state are established in a regularized way, which is convenient for the computer to generate the simulation program automatically.

1.3 Data-Flow Programming and Graphical Language

Dataflow programming is a typical programming diagram that presents the directed data and energy flow between the operations [19]. LabVIEW is chosen to be the platform for the demonstration in the dissertation because of its visual characteristics and the variety of functions integrated [20].

Graphical language such as images can stimulate people's visual pleasure [21], mobilize visual all-round cognition, and at the same time it has irreplaceable advantages in value communication [22].

These are advantages of the graphical language in the following [23, 24]:

- Images are the most concise and fastest visual information communication language;
- Images are the most expressive visual language that can be easily recognized and remembered;
- Images are a world language that transcends national barriers

The Bond Graph as a visual language contains the main advantage of the graphical language, for this reason, the students could have a better memory of the new contents. In the meantime, the Bond Graph has a modular property, which makes the contents easily mastered by pieces.

1.4 Application of Bond Graph Representation

Linear control theory is a simple and relatively mature branch of modern control theory. The Proportional–Integral–Derivative (PID) controller is widely used as a typical controller in the linear control system. [25][26]. In industrial process control, PID control has the advantages of a simple principle, strong robustness, and a wide range of practicality. It is regarded as a mature technology and the most widely used control system [27].

One of the most typical nonlinear controllers is the sliding mode controller (SMC). The sliding mode controller is a typical controller that is easy to apply from a mechatronics point of view but sophisticated to analyze in terms of mathematical theory. Sliding mode control is a kind of nonlinear control realized by switching function, which has been widely used in various industrial control objects in terms of the relatively complete theoretical system [28].

In the dissertation, the PID controller and the SM controller are first represented by applying the amplifier using the Bond Graph. Since the Bond Graph handles all forms of energy systems, the Lagrange equations can be applied to any system represented by the Bond Graph.

2 Aim of the Dissertation

Some obstacles need to be overcome during the study of mechatronics engineering, the complexity of the theory, and the conversion from the schematic to the simulation code. The dissertation proposes the Bond Graph as a novel teaching method to help mechatronics engineering students overcome these obstacles.

It is hard to understand the theoretical interdisciplinary subjects in mechatronics engineering based on the responses from the students. The Bond Graph has been proposed to apply to mechatronics engineering education, which could make difficult subjects easier for the students. The Bond Graph as a graphical language provides a modular method to divide the complex content into blocks. Mechatronics students

can master the knowledge piece by piece, and then combine the modular knowledge to have the whole picture of the system.

The Bond Graph provides students with a shorter learning curve compared with traditional mathematics methods such as Ordinary differential equations(ODE) and state space. With the help of the Bond Graph, the students and the researchers could simulate the dynamic system without using traditional methodologies. Compared with the complex traditional mathematical methods, the Bond Graph could help students save calculating time to efficiently get the dynamic system's block diagram with a shorter learning curve during their studies.

This dissertation presents the numerical and analytical of the dynamic system in mechatronics engineering. The numerical part is the mathematical method representation of the dynamical system and examples. The analytical part is a novel graphical language representation using the Bond Graph.

It has been proved that the Bond Graph is more acceptable than the traditional mathematical methods to the mechatronics engineering students based on the final test results of the mechatronics engineering students over three years.

3 Applied Methods

The traditional mathematical equations result in input and output relations. It also describes how the system operates in multiple domains. With the introduction of the basics of the Bond Graph, which provides a generalized tool to analyze multiple dynamic systems.

3.1 Bond Graph Modeling Method

There are three branches of the bond graph elements, passive elements, active elements, and junctions. The passive elements contain 1-port element relating the power and energy variables.

The summary of the elements in the Bond Graph can be illustrated in the

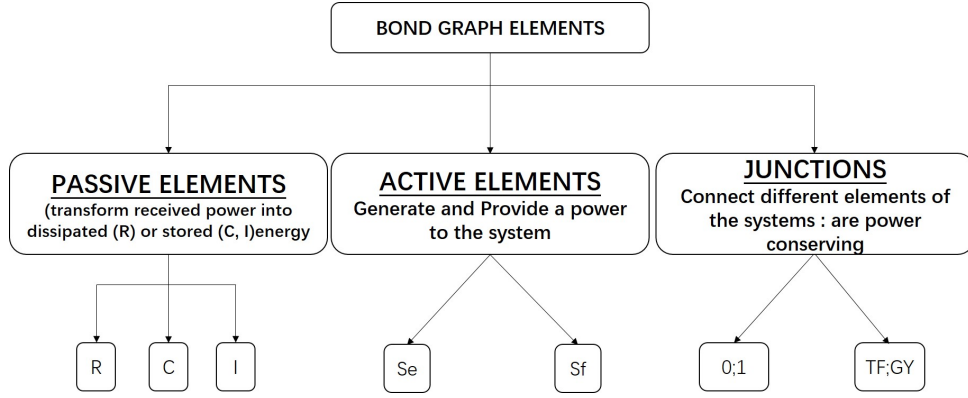


Figure 1. *Bond graph elements*

following: The passive elements can transform received power into dissipated or stored energy, and the active elements can generate and provide power to the system. The function of the junctions is to connect different elements of the systems. The branches are shown in figure 1.

The constitutive relations of the R, C, I elements are shown in Table 1. The R elements present the relation of the linear systems and the C and I elements illustrate the integral relations of the components in the system.

Table 1. *Constitutive relations for R, C, I*

Constitutive relations for R,C,I	R	C-integral	I-integral
Generalized	$f = \frac{e}{R}$	$e = \frac{\int f dt}{C}$	$f = \frac{\int e dt}{I}$
Translational	$v = \frac{F}{b}$	$F = k \int v dt$	$v = \frac{\int F dt}{m}$
Rotational	$\omega = \frac{\tau}{\beta}$	$\tau = \kappa \int \omega dt$	$\omega = \frac{\int \tau dt}{J}$
Electrical	$i = \frac{e}{R}$	$e = \frac{\int i dt}{C}$	$i = \frac{\int e dt}{L}$
Hydraulic	$Q = \frac{P}{R_f}$	$P = \frac{\int Q dt}{C_f}$	$Q = \frac{\int P dt}{I_f}$

The Following is the 1-port list and its characteristics:

- R-element: The characteristic is related to the effort and flow directly.
- C-element: The basic elements could store the potential energy. It relates effort to generalized displacement directly.

- I-element: The basic elements could store the kinetic energy. It relates momentum to flow directly.

3.2 Applied Methodologies

There are other methodologies applied in the Bond Graph such as Kirchhoff's circuit laws, Newton's second law, free body diagram, Lagrangian equation, etc.

Kirchhoff's Circuit Law

Kirchhoff's Circuit Law is one of the important principles in Bond Graph modeling. The active element, junction, and passive junction could consist of the simple Bond Graph of a dynamic system. A simple Bond Graph will be demonstrated in the following Figure 2.

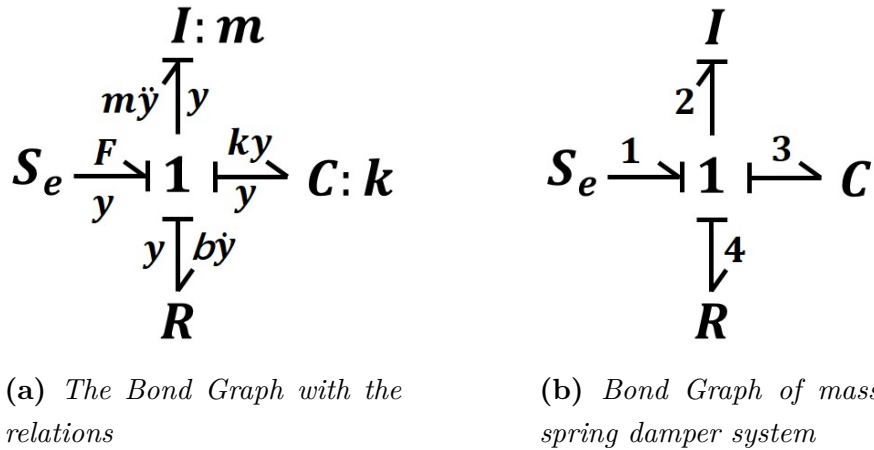


Figure 2. *The schematic and the Bond Graph of the mass-spring-damper system*

Figure 2 (a) shows the Bond Graph with the mathematical relation of the dynamic system. The numbers above arrow in Figure 2 (b) is convenient for the modeling in the following:

First, make all the arrows in a sequence.

Second, check the junction type in the Bond Graph. Since it is a 1 – *junction* in the Bond Graph, then do the summation of the effort.

Third, make the relation between all the elements based on Kirchhoff's Circuit Law. The sum of the inputs is equal to the sum of the output, which is decided by the direction of the arrows.

$$e_1 = e_2 + e_3 + e_4 \quad (1)$$

The fourth step, check the causality in the Bond Graph to make sure the real output of the dynamic system. The causality is the direction of the effort. In Figure 2 (b), the e_2 is the output.

$$e_2 = e_1 - e_3 - e_4 \quad (2)$$

The relation shown in the equation 2 is the key to converting the dynamic system into the block diagram using Bond Graph modeling simulation. The complex Bond Graph analysis is based on the steps above logical.

Arrows and Causality

The Figure 3 shown in the following is a typical DC electrical machine Bond Graph.

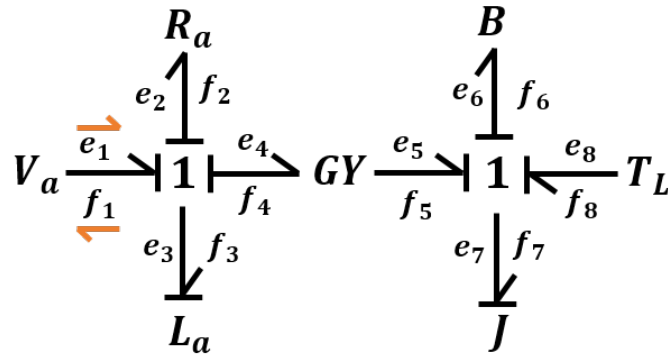


Figure 3. *Bond Graph of the DC electrical Machine*

V_a donates the voltage in the electrical circuit, R_a and L_a are the resistor and inductor in the circuit. GY represents the rotor in the DC electrical machine, B and J are the bearing and inertia in the mechanical system. T_L is the torque load.

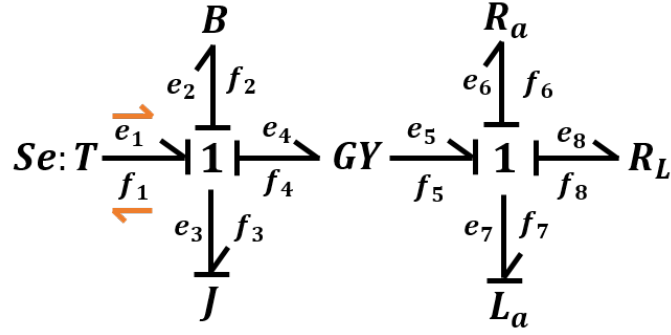


Figure 4. *Bond Graph of Generator*

Notice the direction of arrows around the GY , the representation of the Bond Graph means different if the arrows' directions are changed. The Figure 4 is shown in the following:

Table 2. *Direction of the Bond Graph Causality*

R		
I		
C		

The bond arrows and the causality play critical roles in the Bond Graph. The same representation can display different dynamic systems in multiple domains. In the meantime, the performance of the Bond Graph with different causalities is significantly different. The arrow of the Bond Graph represents the energy direction, which decides the energy conversion between different domains. In the meantime,

the causality represents the direction of the effort, which shows the different calculations in Table 2.

3.3 Opeartion Amplifier Applied in PID and SMC Bond Graph Represetation

Operational amplifiers(op-amps) are widely used in many electronic applications. OP-amps can be considered as the core of signal applications, such as amplifiers, integrators, and differentiators. The op-amps can provide extra functions based on the different conditions of the different components.

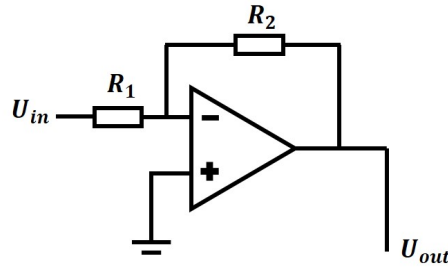


Figure 5. *simple operational amplifier*

The operation amplifier is a good teaching material in the mechatronics engineering subjects. The operational amplifier is shown in Figure 5 and 6.

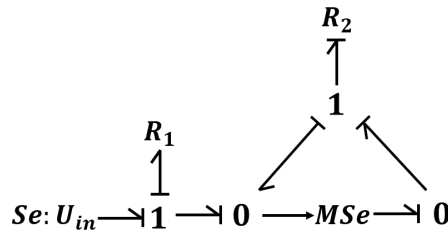
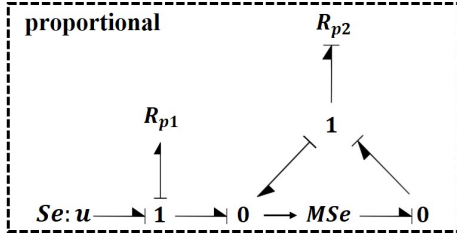
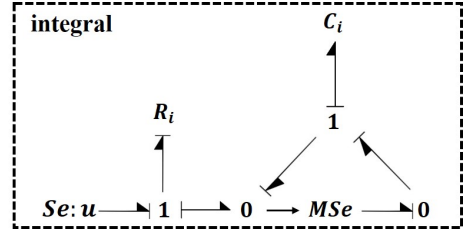


Figure 6. *Bond Graph of operational amplifier*

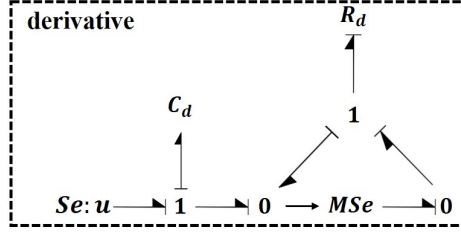
In realistic applications, an operational amplifier(op-amp) is used with the resistors, and capacitors connected as a feedback circuit. The Bond Graph representation of the Inverting Operational Amplifier is shown in Figure 6 [2].



(a) *simple inverting operational amplifier*



(b) *Bond Graph of integral operational amplifier*



(c) *Bond Graph of derivative operational amplifier*

Figure 7. *proportional, integral, derivative Operational Amplifier and its Bond Graph*

Numerical and Analytical Representation of the Inverse disturbance observer

The simplified motor model is shown in equations 3 and 4, where the input and output are described using u and y . The nominal parameters T_n and G_n are used in the inverse disturbance observer model. The d is the disturbance signal and it is estimated by $\hat{d}$.

$$y(s) = \frac{G_m}{1 + sT_m}(u(s) + d(s)) \quad (3)$$

$$d = \frac{1 + sT_m}{G_m}y - u \quad \hat{d} = \frac{1 + sT_n}{G_n}y - u \quad (4)$$

The main operation principle of the simple disturbance observer can be described in Figure 8. The mechanical time constant T_m and the gain G_m consist of the motor model in the upper part of the block diagram. The T_n and the G_n are the estimated reciprocal of the motor model in the lower part of the block diagram.

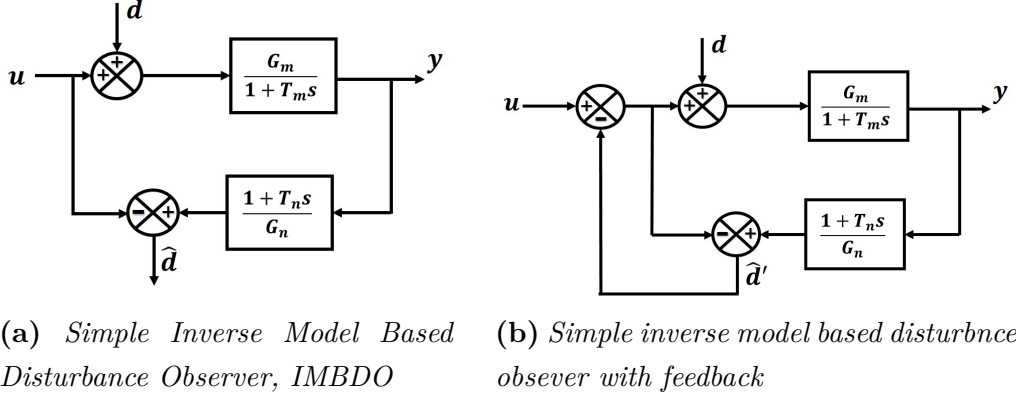


Figure 8. *Inverse model disturbance observer*

3.4 Physics Newton's Second Law and Mechanism Lagrangian

Newton's second law and physics analysis are the main tools to build the Bond Graph. The Lagrange plays an important role in the mechanism domain. The numerical part of the Lagrangian equations can be illustrated in the following. If we consider the system as a set of prime points, and the position of each of the prime points can be determined by several independent generalized coordinates, q_i , and as a function of time t , then the change of the whole system with time can be described by the function $q_i(t)$. Denoting the derivative of $q_i(t)$ with respect to time as $\dot{q}_i$, each $q_i(t)$ can be solved by the Lagrange equation if all $q_i, \dot{q}_i$ at the initial moment are given:

$$\frac{d}{dt} \frac{\partial L}{\partial \dot{q}_i} = \frac{\partial L}{\partial q_i} \quad (i = 1, 2, 3, \dots, N) \quad (5)$$

Where, L is the lagrangian of the system, which is equal to the difference between the kinetic energy of the system and the potential energy. We consider the q_i and $\dot{q}_i$ as the q and $\dot{q}$ for the convenience. Then the Lagrangian of the system is shown in the equation 6.

$$L(q, \dot{q}, t) = T(q, \dot{q}, t) - V(q, t) \quad (6)$$

Where the T donates the kinetic energy of the system, V is the potential energy of the system. If there is a conserved quantity in the system called $\frac{\partial L}{\partial \dot{\theta}}$, as the θ corresponds to zero on the right side of the Lagrangian equation.

$$\frac{d}{dt} \frac{\partial L}{\partial \dot{\theta}} = \frac{\partial L}{\partial \theta} = 0 \quad (7)$$

In this case, if the Lagrangian is independent of a generalized coordinate q_i , then the generalized momentum p_i is a conserved quantity, which is called a cyclic coordinate. The generalized momentum known as conjugate momentum is defined as:

$$p_i = \frac{\partial L}{\partial \dot{q}_i} \quad (8)$$

The Bond Graph of the Lagrange equation can be represented in Figure 9 based on the theory of the Lagrangian equations above.

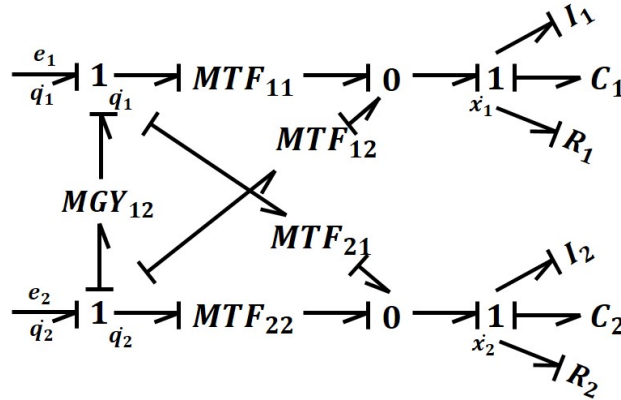


Figure 9. *general Lagrangian bond graph [29]*

The Lagrangian Bond Graph above is detailed but complicated, so it is necessary to introduce a simplified version. Before introducing the alternate form of the Lagrangian bond graph, the C-field bond graph should be illustrated in the following Figure 10.

There are two sources of effort as the inputs, which are the two independent generalized coordinates. In the meantime, the passive element is the compliance.

This simplification version is the compliance field or C-field. The Inertance field shares the same logic as the compliance field.

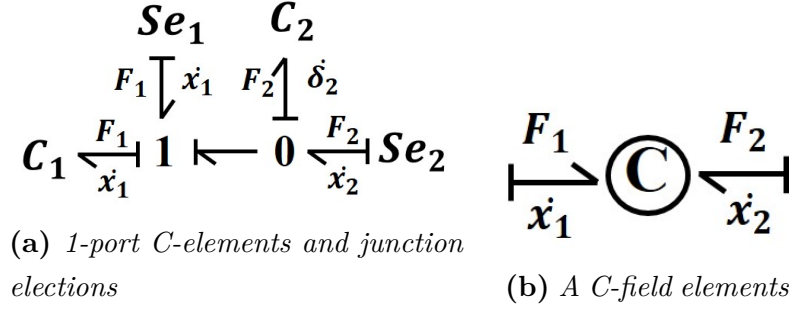


Figure 10. 1-port C-element and c-field element

There is a simplified form of the Lagrange bond graph. The Lagrangian Bond Graph obeys the same theory as the compliance field. The Lagrangian Bond Graph in Figure 9 could be simplified to the alternate form of the Lagrangian bond graph as Figure 11.

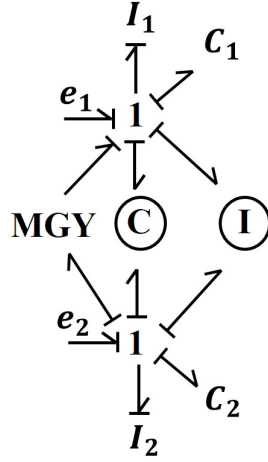


Figure 11. Lagrangian bond graph alternate form [29]

Lagrange's equations are a powerful method for the modeling in many fields. Lagrange's equations can represent the energy and power involving only generalized displacements and velocities. The bond graph is also a powerful tool in the modeling subject by the graphical language of the energy storages and the effort flows.

4 Outcome Results

In control theory, linear control is one of the fundamental control strategies, and in the meantime, the PID controller is a classical controller for the DC machine speed control in the linear control domain.

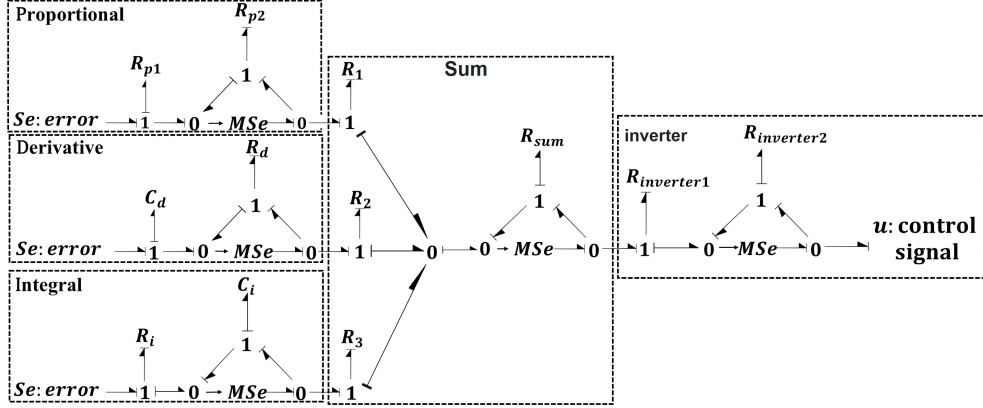


Figure 12. *PID representation using Bond Graph*

PID controller can be represented using the operational amplifiers bond graph separately. The bond graph of the PID controller contains an inverter operational amplifier, differential operational amplifier, and integral operational amplifier. The bond graph of the PID controller is shown in Figure 12.

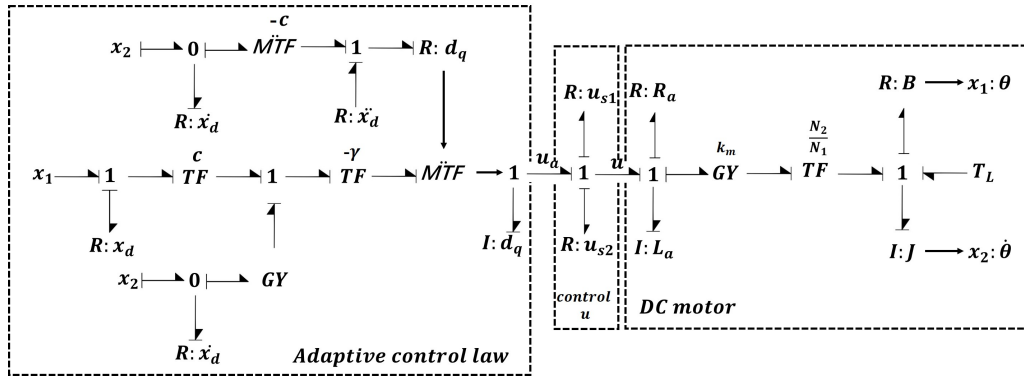


Figure 13. *Bond Graph of adaptive control law*

One of the main contributions of the dissertation is to introduce the way to represent sliding mode by using the Bond Graph method. Compared with the

mathematical equations, the Bond Graph method above presents all the energy flow of the adaptive robust sliding mode control.

The elements R and I are the type of energy in the bond graph. MTF is the modulated transformation, it can be considered as a gain in the bond graph. $x_1 : \theta$ and $x_2 : \dot{\theta}$ are the position and speed respectively in the control loop. $x_d : \theta_d$ is the ideal position input. The block diagram of the adaptive control in LabVIEW is shown in Figure 14.

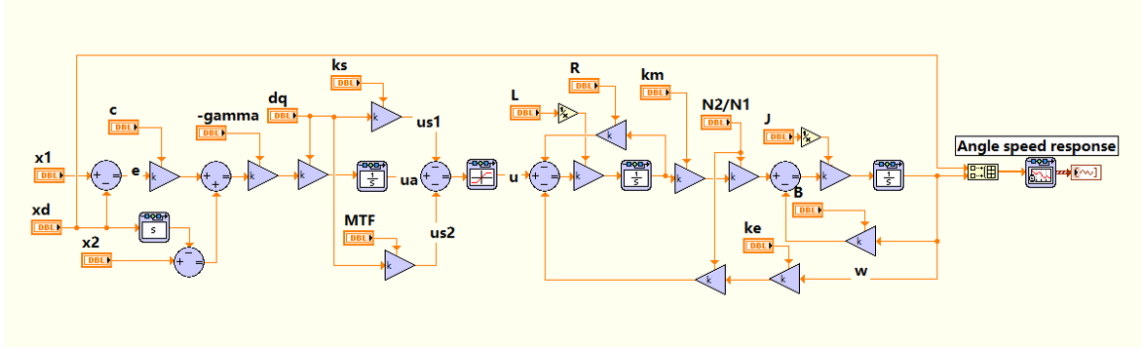


Figure 14. Block diagram of adaptive control in LabVIEW

The Bond Graph of the inverse disturbance observer is shown in figure 15

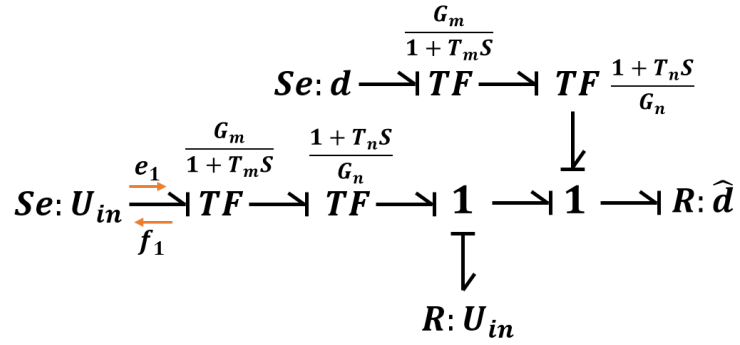


Figure 15. Bond Graph inverse disturbance observer

The Bond Graph shown in Figure 16 is based on the structure of Figure 15. The first $1 - junction$ inside is the feedback loop in the block diagram 8(b). The red arrows show the direction of the effort and flow. The causality means the direction of the effort, and the direction of the flow is opposite to the effort.

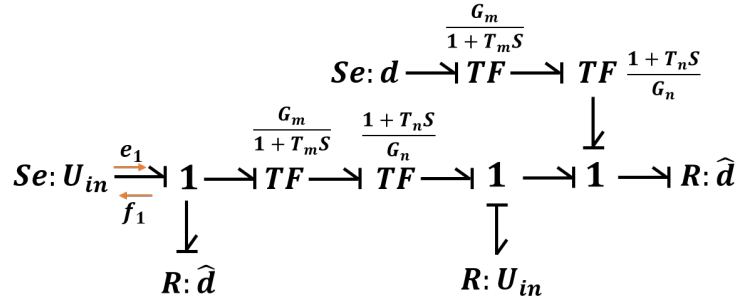


Figure 16. *Bond Graph simple inverse model based disturbance observer with feedback*

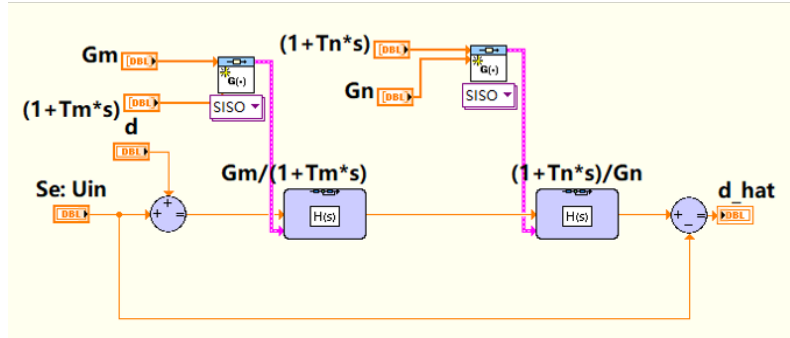


Figure 17. *Block diagram of simple inverse model based disturbance observer*

The block diagram representation of the inverse disturbance observer is shown in Figure 17. The inverse disturbance observer with the feedback can be described in Figure 18. In the LabVIEW programming, the feedback node is for avoiding the error to fulfill the completion of the programming.

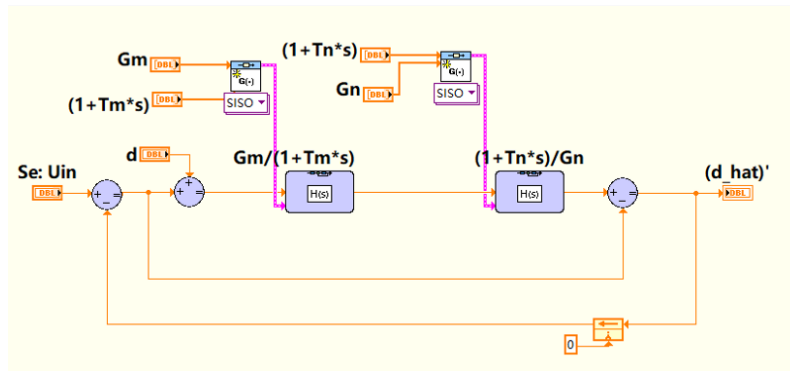


Figure 18. *Block diagram of simple inverse model based disturbance observer with feedback*

5 Main Claims

With the development of technology, the control theory has been well-developed in recent years. The control theory appears in the human's daily life. The modeling and simulation are considered critical processing in the control theory, both in the theoretical and the practical. For the traditional education in mechatronics engineering subjects, mathematics is essential for research and education.

Based on the responses of the students, it is hard to understand and digest the concept of the complex mathematics theory. Then the Bond Graph is necessary for the students and teachers. The students could have a better understanding of the knowledge with the help of the Bond Graph and a quick solution to the questions. The teachers can have a graphical tool to present the dynamic control system from another perspective.

The Bond Graph can be considered as a handy graphical language to express the details from a visual point of view. In this case, the Bond Graph can assist students in understanding mathematics calculations, but it is not an alternative solution to traditional methods. The Bond Graph can apply to many fields, such as mechanical electrical, and hydraulic systems. This property of the Bond Graph presents the synergy of mechatronics engineering. The PID controllers, sliding mode controller, inverse, and direct disturbance observer can be represented using the Bond Graph. The Lagrangian Bond Graph provides an alternative method to express the complexity of the Lagrange equations.

Lastly, a three-year test has proven that the Bond Graph is more acceptable than the traditional mathematical method for mechatronics engineering students.

6 Claims of Dissertation

The problems and claims are shown in these categories in the following:

Thesis 1: [P1] [P3] [P5] on page 21

Based on findings and Mechatronics engineering educational experience, the Bond Graph is recognized as an effective graphical tool for teaching PID and sliding mode control in Mechatronics [P1, P3]. The Bond Graph simplifies mechatronics modeling teaching methods for undergraduate students by combining modular design and visual programming language [P1, P3, P5]. Bond Graph-based graphical model representation is a novel education method as an intuitive and native language of the Mechatronics Engineering undergraduate education field, a three-year test finding from the mechatronics engineering students has proved its efficiency. Overall, a pure graphical-based educational modeling method had been proposed and verified by processes including Schematic – Bond Graph – Block Diagram – Block-oriented code. The test results are the following [P1]: [Three years students mod and sim test results](#)

Thesis 2: [P2] [P4] [P5] on page 21

The inverse disturbance observer, as a complex case study for mechatronics education, can be replaced by the direct disturbance observer[P2]. Compared with the inverse disturbance observer, the direct disturbance observer has a better performance without the additional filter. Additionally, the Bond Graph provides a unified graphical module representation for these two disturbance observers, enhancing the effectiveness of mechatronics education [P4, P5]. Furthermore, the Bond Graph with causalities is utilized by the modularity theory for data flow-oriented programming languages in mechatronics education [P4, P5]. In the meantime, the Bond Graph method has been validated by the unique representation of the disturbance observer [P4, P5].

Thesis 3: [P1] [P3] [P4] [P5] on page 21

The dissertation proposes to use the Bond Graph to modularize the modeling and simulation and enhance mechatronics education by representing traditional formulas visually [P3]. Throughout three years of mechatronics education, the Bond Graph has proven to be beneficial to mechatronics education [P1, P5]. Based on the students' feedback, and published papers accepted by international journals, the Bond Graph is effective for force analysis in modeling and simulation [P1, P4]. In addition, the Lagrangian Bond Graph offers Mechatronics students a simple alternative method to traditional energy analysis for presenting the energy of spatial dynamics [P5]. The “Bond Graph benefits Mechatronics education method” theory was accepted by the Industrial Electronics Society (IES) and Student & Young Professionals Activity (S & YPA) [P5].

Publications

- P1: Guo, Z., Korondi, P., & Szemes, P. T. (2023). Bond-Graph-Based Approach to Teach PID and Sliding Mode Control in Mechatronics. *Machines*, 11(10), 959. [doi:org/10.3390/machines11100959](https://doi.org/10.3390/machines11100959).
- P2: Fink, N., Zenan, G., Szemes, P., & Korondi, P. (2023). Comparison of Direct and Inverse Model-based Disturbance Observer for a Servo Drive System. *Acta Polytechnica Hungarica*, 20(4). [doi:10.3390/machines11100959](https://doi.org/10.3390/machines11100959).
- P3: G. Zenan, P. T. Szemes and P. Korondi, "Bond graph-based teaching method to enhance the synergy of mechatronics in Lab VIEW," 2022 IEEE 9th International Conference on e-Learning in Industrial Electronics (ICELIE), Brussel, Belgium, 2022, pp. 1-6. [doi:10.1109/ICELIE55228.2022.9969437](https://doi.org/10.1109/ICELIE55228.2022.9969437).
- P4: Zenan, G, and Péter Tamás SZEMES. "Hydraulic system with PID control under photovoltaic panel supply using LabVIEW." In 2020 3rd International Symposium on Small-scale Intelligent Manufacturing Systems (SIMS), pp. 1-6. IEEE, 2020. [doi:10.1109/SIMS49386.2020.9121415](https://doi.org/10.1109/SIMS49386.2020.9121415).
- P5: G. Zenan, H. A. Neamah and P. Tamás Szemes, "Bond Graph Benefits the Education in Mechatronics Engineering," 2024 IEEE 21st International Power Electronics and Motion Control Conference (PEMC), Pilsen, Czech Republic, 2024, pp. 1-6, [doi:10.1109/PEMC61721.2024.10726329](https://doi.org/10.1109/PEMC61721.2024.10726329).

REFERENCES

- [1] R. H Bishop. *"Mechatronics: an introduction"*. CRC Press, 2017. DOI: <https://doi.org/10.1201/9781420037241>.
- [2] D Shuvra. *"Mechatronic modeling and simulation using bond graph"*. CRC Press, 2009, p. 1. DOI: <https://doi.org/10.1201/b15831>.
- [3] Clarence W D Silva. *"Mechatronic systems: devices, design, control, operation and monitoring"*. CRC press, 2007. DOI: <https://doi.org/10.1201/9780849307768>.
- [4] William B. *"Mechatronics: electronic control systems in mechanical and electrical engineering"*. Pearson Education, 2003. ISBN: 978-1-292-08159-5.
- [5] David B and David W R. "Mechatronics in action". In: *Case Studies in Mechatronics–Application and Education/D. Bradley, DW Russel.–London: Springer-Verlag London Limited* (2010). DOI: <https://doi.org/10.1007/978-1-84996-080-9>.
- [6] R. H Bishop. *"The mechatronics handbook-2 volume set"*. CRC press, 2002. DOI: <https://doi.org/10.1201/9781420042450>.
- [7] G Marzano, A Martinovs, and S Ušča. "Mechatronics education: needs and challenges". In: *ENVIRONMENT. TECHNOLOGIES. RESOURCES. Proceedings of the International Scientific and Practical Conference*. Vol. 2. 2019, pp. 214–217. DOI: <https://doi.org/10.17770/etr2019vol2.4199>.
- [8] W Borutzky. *"Bond graph modelling of engineering systems"*. Vol. 103. Springer, 2011. DOI: <https://doi.org/10.1007/978-1-4419-9368-7>.
- [9] W Borutzky. *Bond graph methodology: development and analysis of multidisciplinary dynamic system models*. Springer Science & Business Media, 2009. DOI: <https://doi.org/10.1007/978-1-84882-882-7>.
- [10] G A Raiker, L Umanand, and B S Reddy. "Bond Graph Approach for Modelling Solar PV-Thermal and Thermoelectric Devices". In: *2020 IEEE International Conference on Electronics, Computing and Communication Technologies (CONECCT)*. IEEE. 2020, pp. 1–3. DOI: <https://doi.org/10.1109/CONECCT50063.2020.9198622>.
- [11] J U Thoma. *"Introduction to bond graphs and their applications"*. Elsevier, 2016. DOI: <https://doi.org/10.1016/B978-0-08-018881-2.50007-6>.
- [12] W Borutzky. "Bond graph model-based fault accommodation in power electronic systems". In: *2015 23rd Mediterranean Conference on Control and Au-*

- tomation (MED). IEEE. 2015, pp. 68–75. DOI: <https://doi.org/10.1109/MED.2015.7158731>.
- [13] J K Sagawa and M S Nagano. “Applying bond graphs for modelling the manufacturing dynamics”. In: *IFAC-PapersOnLine* 48.3 (2015), pp. 2047–2052. DOI: <https://doi.org/10.1016/j.ifacol.2015.06.390>.
 - [14] M Louzazni et al. “Bond graph modelling of different equivalent models of photovoltaic cell”. In: *Procedia Manufacturing* 32 (2019), pp. 802–809. DOI: <https://doi.org/10.1016/j.promfg.2019.02.288>.
 - [15] Vjekoslav Damic and John Montgomery. “*Mechatronics by bond graphs: an object-oriented approach to modelling and simulation*”. Springer, 2016. DOI: <https://doi.org/10.1007/978-3-662-49004-4>.
 - [16] A.C. van der Klauw P.P.J. van den Bosch. “*Modeling, identification and simulation of dynamical systems*”. crc Press, 2020. DOI: <https://doi.org/10.1201/9780138746872>.
 - [17] Jan F Broenink. “Introduction to physical systems modelling with bond graphs”. In: *SiE whitebook on simulation methodologies* 31.2 (1999). URL: <https://api.semanticscholar.org/CorpusID:15129050>.
 - [18] F Merahi, B O Bouamama, and S Mekhilef. “Bond graph modeling, design and experimental validation of a photovoltaic/fuel cell/electrolyzer/battery hybrid power system”. In: *International journal of hydrogen energy* 46.47 (2021), pp. 24011–24027. DOI: <https://doi.org/10.1016/j.ijhydene.2021.05.016>.
 - [19] Tiago Boldt Sousa. “Dataflow programming concept, languages and applications”. In: *Doctoral Symposium on Informatics Engineering*. Vol. 130. 2012. URL: https://paginas.fe.up.pt/~prodei/dsie12/papers/paper_17.pdf.
 - [20] Rick Bitter, Taqi Mohiuddin, and Matt Nawrocki. “*LabVIEW: Advanced programming techniques*”. CRC press, 2017. DOI: <https://doi.org/10.1201/9780849333255>.
 - [21] M Massironi. “*The psychology of graphic images: Seeing, drawing, communicating*”. Psychology Press, 2001. DOI: <https://doi.org/10.1068/p3207rvw>.
 - [22] G Costagliola et al. “Visual languages: A graphical review”. In: *Information Visualization* 17.4 (2018), pp. 335–350. DOI: <https://doi.org/10.1177/1473871617714520>.
 - [23] Kim Marriott and Bernd Meyer. “*Visual language theory*”. Springer Science & Business Media, 1998. DOI: <https://doi.org/10.1007/978-1-4612-1676-6>.
 - [24] M Twyman. “A schema for the study of graphic language (tutorial paper)”. In: *Processing of visible language* (1979), pp. 117–150. DOI: https://doi.org/10.1007/978-1-4684-0994-9_8.
 - [25] V K Suman S Kand Giri. “Speed control of DC motor using optimization techniques based PID Controller”. In: *2016 IEEE International Conference on Engineering and Technology (ICETECH)*. IEEE. 2016, pp. 581–587. DOI: <https://doi.org/10.1109/ICETECH.2016.7569318>.
 - [26] A Abdulameer et al. “Tuning methods of PID controller for DC motor speed control”. In: *Indonesian Journal of Electrical Engineering and Computer Sci-*

- ence 3.2 (2016), pp. 343–349. DOI: <https://doi.org/10.11591/ijeecs.v3.i2.pp343-349>.
- [27] K H Ang, G Chong, and Y Li. “PID control system analysis, design, and technology”. In: *IEEE transactions on control systems technology* 13.4 (2005), pp. 559–576. DOI: <https://doi.org/10.1109/TCST.2005.847331>.
 - [28] W Perruquetti and J Barbot. “*Sliding mode control in engineering*”. CRC press, 2002. DOI: <https://doi.org/10.1201/9780203910856>.
 - [29] F T Brown. “Hamiltonian and Lagrangian bond graphs”. In: *Journal of the Franklin Institute* 328.5-6 (1991), pp. 809–831. DOI: [https://doi.org/10.1016/0016-0032\(91\)90056-9](https://doi.org/10.1016/0016-0032(91)90056-9).



Registry number: DEENK/553/2024.PL
Subject: PhD Publication List

Candidate: Guo Zenan
Doctoral School: Doctoral School of Informatics
MTMT ID: 10070881

List of publications related to the dissertation

Foreign language scientific articles in Hungarian journals (1)

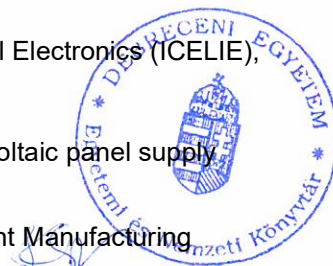
1. Fink, N., **Zenan, G.**, Szemes, P. T., Korondi, P.: Comparison of Direct and Inverse Model-based Disturbance Observer for a Servo Drive System.
Acta Polytech. Hung. 20 (4), 205-228, 2023. ISSN: 1785-8860.
DOI: <http://dx.doi.org/10.12700/APH.20.4.2023.4.12>
IF: 1.4

Foreign language scientific articles in international journals (1)

2. **Zenan, G.**, Korondi, P., Szemes, P. T.: Bond-Graph-Based Approach to Teach PID and Sliding Mode Control in Mechatronics.
Machines. 11 (10), 1-19, 2023. EISSN: 2075-1702.
DOI: <http://dx.doi.org/10.3390/machines11100959>
IF: 2.1

Foreign language conference proceedings (3)

3. **Zenan, G.**, Neamah, H. A., Szemes, P. T.: Bond Graph Benefits the Education in Mechatronics Engineering.
In: 2024 IEEE 21st International Power Electronics and Motion Control Conference, -, [Epub ahead of print], 1-6, 2024.
4. **Zenan, G.**, Szemes, P. T., Korondi, P.: Bond graph-based teaching method to enhance the synergy of mechatronics in LabVIEW.
In: 2022 IEEE 9th International Conference on e-Learning in Industrial Electronics (ICELIE), IEEE, Piscataway, 1-6, 2022. ISBN: 9781665489904
5. **Zenan, G.**, Szemes, P. T.: Hydraulic system with PID control under photovoltaic panel supply using LabVIEW.
In: SIMS 2020 : 3rd International Symposium on Small-scale Intelligent Manufacturing Systems, IEEE, Piscataway, 1-6, 2020. ISBN: 9781728164205





List of other publications

Foreign language scientific articles in international journals (1)

6. **Zenan, G.**, Buchman, A., Szemes, P. T.: Actuator control using TCP IP communication under LabVIEW USB6001 environment.

Carpathian J. Electr. Comp. Eng. 14 (2), 11-14, 2021. ISSN: 1844-9689.

DOI: <http://dx.doi.org/10.2478/cjece-2021-0008>

Total IF of journals (all publications): 3,5

Total IF of journals (publications related to the dissertation): 3,5

The Candidate's publication data submitted to the iDEa Tudóstér have been validated by DEENK on the basis of the Journal Citation Report (Impact Factor) database.

07 November, 2024

