**LEMBAR**
**HASIL PENILAIAN SEJAWAT SEBIDANG ATAU *PEER REVIEW***
**KARYA ILMIAH : PROSIDING INTERNASIONAL**

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|---|---|---|
| Judul Prosiding (Artikel) | **:** | Spectral theory for self-adjoint linear relation (SALR) on a Hilbert space and its application in homogenous abstract cauchy problem |
| Nama/ Jumlah Penulis | **:** | **Susilo Hariyanto,** R K Sari, Farikhin, Y D Sumanto, Solikhin, A Aziz |
| Status Pengusul | **:** | penulis ke-q |
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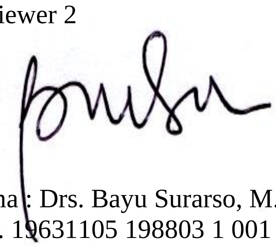

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| b. Ruang lingkup dan kedalaman pembahasan (30%) | 9 | | | 8,975 |
| c. Kecukupan dan kemutahiran data/informasi dan metodologi (30%) | 9 | | | 8,975 |
| d. Kelengkapan unsur dan kualitas terbitan/prosiding (30%) | 9 | | | 8,975 |
| **Total = (100%)** | | | | **29,825** |
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   Atikel sudah ditulis sesuai panduan IOP proceeding dan lengkap dari abstrak hingga kesimpulan. Metodologi yang digunakan berupa studi literatur, namun tidak disampaikan secara eksplisit.

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4. **<u>Kelengkapan unsur dan kualitas terbitan:</u>**
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# Spectral theory for self-adjoint linear relation (SALR) on a Hilbert space and its application in homogenous abstract cauchy problem

Hariyanto S. ; Sari R.K.; Farikhin; Sumanto Y.D.; Solikhin; Aziz A.
Save all to author list

[a] Department of Mathematics, Faculty of Science and Mathematics, Diponegoro University, Semarang, Indonesia



## Abstract

A spectral theory studies eigenvalues and eigenvectors of SALR on H. SALR on Hilbert space H is a linear relation satisfying A = A*. Many applications of SALR on quantum theory, such as the homogenous abstract Cauchy problem.If M is an operator that has an inverse then eigenvalues and eigenvectors are easily determined, but If M is an operator that does not have an inverse then eigenvalues and eigenvectors are quite difficult determined. One way that can be done is to use a linear relation. Furthermore, there are some properties of spectral theoryof linear operator that can not apply to SALR. This paper aims to give a spectral theory for SALR and its application in a homogenous abstract Cauchy problem. © Published under licence by IOP Publishing Ltd.

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## Preface

It is a very great privilege for Faculty of Mathematics and Natural Science (FMIPA) Universitas Negeri Semarang to host the 5th International Conference on Mathematics, Science, and Education (ICMSE 2018) in Kuta, Bali, Indonesia on 8-9 October 2018. We are honored to have the opportunity to work with Indonesian Chemical Society, Indonesian Physical Society, Indonesian Biology Society, Association of Computer Science Higher Education, Indonesian Mathematical Society, and Association of Indonesian Science Educator in this forum. In 2018, our theme of "Collaborative Research on Science, Mathematics, and Education: Its Application As The Development of Sustainable Resources" celebrates the annual conference to provide a platform to the researchers, experts and practitioners from academia, governments, NGOs, research institutes, and industries to meet and share cutting-edge progress in the field of mathematics, natural science, and science education. Also, this event provides an opportunity to enhance understanding of relationships between knowledge and research in the scope of Mathematics, Biology, Chemistry, Physics, and Science Education.

The committee of ICMSE 2018 would like to express the sincere gratitude to the keynote speakers and all authors of the contributed papers in the conference proceedings. Moreover, would like to thank the expert reviewers for reviewing the manuscripts. We also highly appreciate the assistance offered by many volunteers in the preparation of the conference and the proceedings, and of course, to the sponsors assisting in funding this conference.

The committee selected papers and report findings presented in this forum to be published in **Journal of Physics: Conference Series (Institute of Physics Publisher)** indexed in some databases, including the Conference citation index, Scopus, Inspec, Chemical Abstracts Service, and Astrophysics Data System. We hope that this program will expand the mutual understanding and respect in stimulating research in Mathematics, Science, and Education; share research interest and information, and create a form of collaboration and build a trust relationship. We are delighted to be able to show the world what recent developments in the field of Mathematics, Natural Science, and Science Education through this fruitful program.

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## Papers

Journal of Physics: Conference Series **1321** (2019) 022134 doi:10.1088/1742-6596/1321/2/022134

# Learning differential calculus using self-regulated flipped classroom approach

**A Istiandaru[1,*], F Setyawan[1], A S E Hidayat[2] and V Istihapsari[1]**

[1]Mathematics Education Department of Universitas Ahmad Dahlan, Jalan Prof. Dr.Soepomo, S.H. Warungboto, Yogyakarta, 55164 Indonesia.
[2]Monash University, Scenic Blvd & Wellington Road, Clayton VIC 3800, Australia.

*Corresponding author: afit.istiandaru@pmat.uad.ac.id

**Abstract**. Differential calculus becomes a primary pre-requisite material for every student to start learning calculus. It mainly discusses the concepts and theorems regarding derivative of functions. Many mathematics educators believe that learning differential calculus needs specific conditions and attitude as it cannot be set as rote and procedural learning. This research aims to find out the students' perception towards the implementation of self-regulated flipped classroom approach in their differential calculus class. Thirty-six students participated in the seven meetings of the class and gave their perceptions at the end of every meeting. They were engaged in a various type of learning activities outside the classroom such as setting their own goal, gaining information from many sources, and uploading a video of their presentation, while during the class, they were assessed with an interview confirming their understanding about the topics. The result suggests that the self-regulated flipped classroom approach is promising to maintain the students' right attitude towards differential calculus.

## 1. Introduction

It is common in the Indonesian mathematics education curriculum that differential calculus is the fundamental subject providing provision for the pre-service teachers to learn calculus and real analysis. The subject is usually taught in the early semester in the teacher training period. The differential calculus subject mainly discusses the concepts and theorems regarding the derivative of functions[1]. Prior to this, the knowledge of equations, functions, limit,and continuity are also important as the pre-requisite material.Further, the students discuss the definition of the derivative, the derivatives in trigonometric functions, the chain rule, the higher order derivatives and the application of derivatives. Since the material of differential calculus set the foundation of analytical thinking, this subject becomes the foundation of logical, critical and creative thinking for the students of mathematics education department[2–4].

The importance of the differential calculus material was not followed by the adequate performance of the students. In the latest two years of teaching differential calculus, mainly using the drill method, we found that the students still confused with the concepts. The students' differential calculus learning result in 2016/2017, for example, shows that only 30% of the students could achieve the score more than 70. We discussed this phenomenon with the other lecturers of the differential calculus and it was confirmed that the similar condition happened in all differential calculus classes. From this score, we

# Nationalism and integrity values in teaching-learning process of mathematics at elementary school of Japan

**H Suyitno[1], Zaenuri[1], E Sugiharti[1], A Suyitno[1] and T Baba[2]**

[1] Faculty of Mathematic and Natural Sciences, Universitas Negeri Semarang, Indonesia,
[2] IDEC, Hiroshima University, Japan

*Corresponding author: hhardisunnes@yahoo.com

**Abstract.** The values of Nationalism and Integrity are very important to be grown in the young generation. Japan has succeeded in strengthening those values through education in schools. Therefore, it is necessary to do collaborative research between the Research Team of Universitas Negeri Semarang (UNNES) with the partner lecturer from Hiroshima University, that is Prof. Takuya Baba, Ph.D. The problem: How to integrate the values of Nationalism and Integrity in mathematics teaching-learning process at Miyauchi Elementary School of Hiroshima? The research method uses a qualitative approach with the research subjects of Miyauchi Elementary School teachers were selected. The main activity in Japan: observation, interviews, and Focus Group Discussion (FGD) in Miyauchi Elementary School, guided by the partner lecturer. The results of this research: (1) Nationalism and Integrity values has been instilled through families traditionally. (2) Schools apply Nationalism and Integrity values in real context through the learning process, including in the mathematics learning. (3) Courtesy and discipline were also planted in the classroom and has been entrenched among teacher-students. (4) When the student answers the teacher's question, the students immediately stand up and salute by bowing, then respond.

## 1. Introduction

Schools in Indonesia are currently implementing government programs to cultivate students' character values. There are five main values of the character developed namely: religious, nationalism, autonomy/independent, mutual cooperation, and integrity. Currently schools in Indonesia are starting to implement Strengthening Character Education (PPK). This article, written based on the international collaborative research. Our research team has gone to Hiroshima University with a partner lecturer is Prof. Takuya Baba, Ph.D. Guided by him then the research team conducted next research at Miyauchi Elemetary School of Hiroshima. The study was designed to be implemented for 2 years. Research in the first year focused on the value of nationalism and integrity. This first year of study would like to reveal how the elementary school teachers in Japan integrate the nationalism and integrity values in mathematics learning.

Nationalism is a character value of the way of thinking, behaving, and doing that shows loyalty, caring, and respect which places the interests of the nation and the state above the interests of the self and the group. While Integrity is a character value of the attitude of responsibility as a citizen, actively involved in social life, through the consistency of actions and words based on the truth.

Nationalism and Integrity are very important. Nationalism building and Integrity must be strengthened again in the young generation in Indonesia. And, Japan is a country that teach Nationalism and Integrity values in school specifically in the mathematics learning process from an

# Spectral theory for self-adjoint linear relation (SALR) on a Hilbert space and its application in homogenous abstract cauchy problem

*by* Susilo Hariyanto

# Spectral theory for self-adjoint linear relation (SALR) on a Hilbert space and its application in homogenous abstract cauchy problem

**S Hariyanto[1,*], R K Sari[2], Farikhin[1], Y D Sumanto[1], Solikhin[1] and A Aziz[1]**

[1] Department of Mathematics, Faculty of Science and Mathematics, Diponegoro University, Semarang, Indonesia

[2] Magister Program of Mathematics, Department of Mathematics, Faculty of Science and Mathematics, Diponegoro University, Semarang, Indonesia

*Corresponding author: sus2_hariyanto@yahoo.co.id

**Abstract**. A spectral theory studies eigenvalues and eigenvectors of SALR on $\mathsf{H}$. SALR on Hilbert space $\mathsf{H}$ is a linear relation satisfying $A = A^*$. Many applications of SALR on quantum theory, such as the homogenous abstract Cauchy problem.If $M$ is an operator that has an inverse then eigenvalues and eigenvectors are easily determined, but If $M$ is an operator that does not have an inverse then eigenvalues and eigenvectors are quite difficult determined. One way that can be done is to use a linear relation. Furthermore, there are some properties of spectral theoryof linear operator that can not apply to SALR. This paper aims to give a spectral theory for SALR and its application in a homogenous abstract Cauchy problem.

## 1. Introduction

A linear relation is generally referred to as multivalued linear operator. A linear relation on Hilbert space $\mathsf{H}$ is a subspace of Hilbert space $\mathsf{H} \oplus \mathsf{H}$ [1]. The research about spectral theory of linear relation can be found [1-8]. Arens [1]analyzed spectral theory of SALR considered with an unitary operator through Cayley transformation. Gheorge and Vasilescu [2]founded strong connection between spectral theory of closed linear relation and closed linear operator. Recently, Gheorge and Vasilescu [2] given some properties of closed linear relation. Langer and Textorious [3] analyzed spectral theory of a linear relation associated with minimal self-adjont extension. A spectral theory of linear relation and its application can be found in Baskakov and Chernyshov [4], Baskokov and Zagorskii [5] and Sari, et al [6].

A linear relation has been used anabstract Cauchy problem. An abstract Cauchy problems are often found in chemistry, biology, physics, engineering, ecology, finance, industry, environment, and so on. Consider a homogenousabstract Cauchy problem on Hilbert space

$$\frac{d}{dt}Mr(t) = Lr(t), t \in \mathbb{R}_+ = [0,+\infty) \quad (1)$$
$$r(0) = r_0$$

where $M$ and $L$ arelinear operator on Hilbert space $\mathsf{H}$.Anabstract Cauchy problem is called degenerate if an operator $M$ is not invertible. A Cauchy problem is called nondegenerate if an operator $M$ is invertible. If the $M$ operator has an inverse then the problem (1) can be written in the form:

$$\frac{d}{dt}Mr(t) = Lr(t), t \in \mathbb{R}_+ = [0,+\infty) \quad (2)$$
$$r(0) = r_0$$

where $M$ and $L$ are linear operator on Hilbert space $\mathrm{H}$. Therefore, the determination of eigenvalues and eigenvectors on problem (2) is easy to do. If the operator $M$ does not have an inverse then the problem (1) can be generalized in the form of a linear relation:

$$\frac{d}{dt}r(t) \in \mathrm{A}r(t), t \in \mathbb{R}_+ = [0,+\infty) \quad (3)$$
$$r(0) = r_0$$

where $\mathrm{A} = M^{-1}L$ is SALR on $\mathrm{H}$. Wegive a spectral theory of SALR and its applications in homogenous abstract Cauchy problem.

## 2. Preliminaries

Some notations of linear relation on $\mathrm{H}$ can be seen in [1-4, 9-16]. A definition of linear relation, or relation for short, on Hilbert space $\mathrm{H}$ is as follow

**Definition 1** [1] A linear relation is defined by $\mathrm{A} = \{(w,x): w,x \in \mathrm{H}\}$. The domain of $\mathrm{A}$ is defined by $D(\mathrm{A}) = \{w:(w,x) \in \mathrm{A}\}$. The range of $\mathrm{A}$ is defined by $R(\mathrm{A}) = \{x:(w,x) \in \mathrm{A}\}$. The kernel of $\mathrm{A}$ is defined by $N(\mathrm{A}) = \{w:(w,0) \in \mathrm{A}\}$. The multivalued part of $\mathrm{A}$ is defined by $M(\mathrm{A}) = \{x:(0,x) \in \mathrm{A}\}$.

A identity relation on $\mathrm{H}$ is defined by $I = \{(w,w): w \in \mathrm{H}\}$ and a zero relation is defined by $O = \{(w,0): w \in \mathrm{H}\}$. The class of all linear relation on $\mathrm{H}$ will be denoted by $LR(\mathrm{H})$. An inverse relation on Hilbert space is defined by $\mathrm{A}^{-1} = \{(x,w),(w,x) \in \mathrm{A}\}$. Afterward, the duality of $\mathrm{A}$ and its inverse $\mathrm{A}^{-1}$ is

$$D(\mathrm{A}^{-1}) = R(\mathrm{A}), R(\mathrm{A}^{-1}) = D(\mathrm{A}), N(\mathrm{A}^{-1}) = M(\mathrm{A}), M(\mathrm{A}^{-1}) = N(\mathrm{A}).$$

The following is given the definition of an adjoint relation $\mathrm{A}^*$ on Hilbert space $\mathrm{H}$.

**Definition 2** [9] An adjoint relation of a relation $\mathrm{A}$ on $\mathrm{H}$ isa closed relation denoted by $\mathrm{A}^* = \{(k,l) \in \mathrm{H}^2 : \langle x,k\rangle = \langle w,l\rangle, \forall (w,x) \in \mathrm{A}\}$.

We give the following operations of relation.

**Definition 3** [1] Let $\mathrm{A},\mathrm{B} \in LR(\mathrm{H})$, then the sum $\mathrm{A}+\mathrm{B}$ is defined by

$$\mathrm{A}+\mathrm{B} = \{(w,x+l):(w,x) \in \mathrm{A},(w,l) \in \mathrm{B}\}.$$

The product (composition) $\mathrm{BA}$ is defined by

$$\mathrm{BA} = \{(w,l): \exists x \in \mathrm{H}, (w,x) \in \mathrm{A}, (x,l) \in \mathrm{B}\}.$$

A relation $z\mathrm{A}$ is defined by $z\mathrm{A} = \{(w,zx):(w,x) \in \mathrm{A}\}$ for $z \in \mathbb{C}$. A relation $z-\mathrm{A}$ is defined by $z-\mathrm{A} = \{(w,zw-x):(w,x) \in \mathrm{A}, z \in \mathbb{C}\}$.

The definition of symmetric, self adjoint, isometry, injective, and surjective relation is as follows.

**Definition 4** [9] Let $\mathrm{A}$ isa relation on $\mathrm{H}$, then

symmetric if $\mathrm{A} \subset \mathrm{A}^*$
self-adjoint if $\mathrm{A} = \mathrm{A}^*$
Isometri if $\langle w,k\rangle = \langle x,l\rangle, \forall (w,x),(k,l) \in \mathrm{A}$
Unitary if relation $\mathrm{A}$ is an isometry and $D(\mathrm{A}) = R(\mathrm{A}) = \mathrm{H}$

**Definition 4** [12] Let A isa relation on H, then

Surjective if $R(\mathrm{A}) = \mathrm{H}$
Injective if $N(\mathrm{A}) = \{0\}$
Bounded if $D(\mathrm{A}) = \mathrm{H}$ and $\|\mathrm{A}\| < \infty$

## 3. Result and Discussion

The resolvent set of A is defined in Acharya [9] to be the set $\rho(\mathrm{A}) = \{z \in \mathbb{C} : (z - \mathrm{A})^{-1}$ is bounded linear operator} and its complement is the spectrum of A. The spectrum of A is denoted $\sigma(\mathrm{A})$. A scalar $z$ such that $N(z - \mathrm{A}) \neq \{0\}$ is called an eigenvalue of A. Furthermore, An non zero vector $\boldsymbol{w}$ is called an eigenvector of A related to an eigenvalue $z$. A set of all eigenvalues of A is said the point spectrum $\sigma_p(\mathrm{A})$.Clearly, if $z$ is an eigenvalue of A, then $z$ is elements of spectrum of A [1].

We give the following some Theorems of spectral theory of linear relations.

**Theorem 1**

Given a relation A on H is a self-adjoint. If $w$ is an eigenvector of A corresponding to the eigenvalue $z$ and $\beta$ is an non zero scalar, then $\beta w$ is also an eigenvector of A corresponding to the same eigenvalue.

Proof. Given $w$ is an eigenvector of A corresponding to the eigenvalue $z$. Clearly, a relation $\mathrm{A} = \{(w,x) : w, x \in \mathrm{H}\}$ give $x \in \mathrm{A}w$. Therefore, let $\beta$ is an non zero scalar, then $(\beta w, z\beta w) \in \mathrm{B}$. Clearly, $(\beta w, z\beta w) = (\beta w, \beta z w) \in \beta \mathrm{A} \subset$ Consequently,we get $\beta w$ is an eigenvector of A corresponding to the same eigenvalue.

**Theorem2**

A relation A on H is a self-adjoint. If $w$ is an eigenvector of A then $w$ cannot correspond to more than one eigenvalue of A.

Proof. Take any $w \neq 0$. Let $z_1$ and $z_2$ are two distinct eigenvalues of A corresponding to an eigenvector $w$. Furthermore, we have $(w, z_1 w) \in \mathrm{A}_1$ and $(w, z_2 w) \in \mathrm{A}_2$. So that, we get $\mathrm{A}_1 - \mathrm{A}_2 = \{(w, z_1 w - z_2 w) : (w, z_1 w) \in \mathrm{A}_1, (w, z_2 w) \in \mathrm{A}_2\}$. We get $z_1 w - z_2 w = (z_1 - z_2) w \in (\mathrm{A}_1 - \mathrm{A}_2) w$. Clearly, $w \neq 0$ and $(z_1 - z_2) w = 0$, so that we have $z_1 = z_2$.

**Corrolary3**A relation A on H is a self-adjoint. Eigenvectors $w_1$ and $w_2$ belonging to the two different eigenvalues of $z_1$ and $z_2$ a SALR are orthogonal.

**Theorem 4**Let $\mathrm{A} \in LR(\mathrm{H})$ is a SALR that have an eigenvalue $z$, then an eigenspaces A of are pairwise orthogonal.

Proof.Let $E_1$ and $E_2$ is an eigenspaces of the SALR A on H corresponding to the distinct eigenvalues $\mathrm{A}_1$ and $\mathrm{A}_2$. Let $w_1 \in E_1$ and $w_2 \in E_2$ so that $\mathrm{A}w_1 = zw_1$ and $\mathrm{A}w_2 = zw_2$. Furthermore, we get

$$z_1 \langle w_1, w_2 \rangle = \langle z_1 w_1, w_2 \rangle = \langle \mathrm{A}w_1, w_2 \rangle = \langle w_1, \mathrm{A}^* w_2 \rangle \tag{4}$$

and

$$\mathrm{A}^* w_2 = \overline{z_2} w_2 . \tag{5}$$

From (4) and (5), we have

$$z_1 \langle w_1, w_2 \rangle = \langle w_1, \overline{z_2} w_2 \rangle \Leftrightarrow z_1 \langle w_1, w_2 \rangle = z_2 \langle w_1, w_2 \rangle \tag{6}$$
$$\Leftrightarrow (z_1 - z_2) \langle w_1, w_2 \rangle = 0 .$$

Clearly, $z_1 \neq z_2$ so that $\langle w_1, w_2 \rangle = 0$. Hence $w_1 \perp w_2$ for each $w_1 \in E_1$ and $w_2 \in E_2$. Thus $E_1 \perp E_2$.

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A SALR are widely applied to quantum theory, such as the determination of eigenvalues and eigenvectros on homogenous Abstract Cauchy problems. We give the following examples of homogenous Cauchy problem where $M$ is not invertible.

**Example5:**

Consider the Homogenous abstract Cauchy problem for a linear system on a Hilbert space of continuous function $C[0,1]$:

$$\begin{aligned} &\dot{r}_1(t) = 2r_1(t) - r_2(t) + r_3(t) \\ &\dot{r}_2(t) = r_1(t) + r_3(t) \\ &\dot{r}_3(t) = r_1(t) - r_2(t) + 2r_3(t) \\ &r(0) = r_0 \end{aligned} \tag{7}$$

The problem (7) can be written in the form

$$\begin{aligned} &\frac{d}{dt}Mr(t) = Lr(t), t \in \Box_+ = [0,+\infty) \\ &r(0) = r_0 \end{aligned} \tag{8}$$

where $M = \begin{pmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{pmatrix}$ and $L = \begin{pmatrix} 2 & -1 & 1 \\ 1 & 0 & 1 \\ 1 & -1 & 2 \end{pmatrix}$. Clearly, $M$ is invertible so that a Cauchy problem is a nondegenerate. Furthermore, we get

$$\mathrm{A} = M^{-1}L = \left\{ \left( \begin{pmatrix} w_1 \\ w_2 \\ w_3 \end{pmatrix}, \begin{pmatrix} x_1 \\ x_2 \\ x_3 \end{pmatrix} \right) \in \Box^3 \times \Box^3 : x_1 = 2w_1 - w_2 + w_3, x_2 = w_1 + w_3, x_3 = w_1 - w_2 + 2w_3 \right\} \tag{9}$$

and

$$z - \mathrm{A} = \left\{ \left( \begin{pmatrix} w_1 \\ w_2 \\ w_3 \end{pmatrix}, z\begin{pmatrix} w_1 \\ w_2 \\ w_3 \end{pmatrix} - \begin{pmatrix} 2 & -1 & 1 \\ 1 & 0 & 1 \\ 1 & -1 & 2 \end{pmatrix}\begin{pmatrix} w_1 \\ w_2 \\ w_3 \end{pmatrix} \right) : w_1, w_2, w_3 \in \Box \right\}. \tag{10}$$

Therefore, we get $(z-\mathrm{A})w = 0 \Leftrightarrow \begin{pmatrix} z-2 & 1 & -1 \\ -1 & z & -1 \\ -1 & 1 & z-2 \end{pmatrix}\begin{pmatrix} w_1 \\ w_2 \\ w_3 \end{pmatrix} = 0$. Clearly,we get $z=1$ with $w = \begin{bmatrix} -1 \\ 0 \\ 1 \end{bmatrix}$ and $w = \begin{bmatrix} 1 \\ 1 \\ 0 \end{bmatrix}$, and $z=2$ with $w = \begin{bmatrix} 1 \\ 1 \\ 1 \end{bmatrix}$. Consequently, the point spectrum of $\mathrm{A}$ is $\sigma_p(\mathrm{A}) = \{1,2\}$ .Thus, eigenvalues of relation $\mathrm{A}$ is $z=1$ and $z=2$, while eigenvectors of relation $\mathrm{A}$ is $\left\{ \begin{bmatrix} -1 \\ 0 \\ 1 \end{bmatrix}, \begin{bmatrix} 1 \\ 1 \\ 0 \end{bmatrix}, \begin{bmatrix} 1 \\ 1 \\ 1 \end{bmatrix} \right\}$.

Suppose $z \in \Box$ , we get

$$\left\| z\begin{pmatrix} w_1 \\ w_2 \\ w_3 \end{pmatrix} - \begin{pmatrix} 2 & -1 & 1 \\ 1 & 0 & 1 \\ 1 & -1 & 2 \end{pmatrix}\begin{pmatrix} w_1 \\ w_2 \\ w_3 \end{pmatrix} \right\| \geq |z| \left\| \begin{pmatrix} w_1 \\ w_2 \\ w_3 \end{pmatrix} \right\| - \left\| \begin{pmatrix} 2 & -1 & 1 \\ 1 & 0 & 1 \\ 1 & -1 & 2 \end{pmatrix}\begin{pmatrix} w_1 \\ w_2 \\ w_3 \end{pmatrix} \right\| \tag{11}$$

$$\geq (|z|-2)\left\|\begin{pmatrix} w_1 \\ w_2 \\ w_3 \end{pmatrix}\right\|.$$

We can choose $C(z)=|z|-2>0 \Leftrightarrow |z|>2$. Consequently, the resolvent set of A is the set $\rho(\mathrm{A})=\{z\in\mathbb{C}:|z|>2\}$ and spectrum of A is $\sigma(A)=\{z\in\mathbb{C}:|z|\leq 2\}$.

We give the following examples of homogenous Cauchy problem where operator $M$ is not invertible.

**Example6:**

Consider the homogenous abstract Cauchy problem on a Hilbert space of continuous function $C[0,1]$:

$$\frac{d}{dt}Mr(t)=Lr(t), t\in\mathbb{R}_+=[0,+\infty) \qquad (12)$$
$$r(0)=r_0$$

where $M=\begin{pmatrix} 1 & 0 \\ 0 & 0 \end{pmatrix}$ and $L=\begin{pmatrix} 5 & 4 \\ 3 & 2 \end{pmatrix}$.

Clearly, $M$ is not invertible so that Cauchy problem is a degenerate so that we get

$$\mathrm{A}=M^{-1}L=\left\{\left(\begin{pmatrix} w_1 \\ w_2 \end{pmatrix},\begin{pmatrix} x_1 \\ x_2 \end{pmatrix}\right): w_2=-\frac{3}{2}w_1, x_1=-w_1, \forall\begin{pmatrix} w_1 \\ w_2 \end{pmatrix}\in D(L)\right\} \qquad (13)$$

and

$$z-\mathrm{A}=\left\{\left(\begin{pmatrix} w_1 \\ w_2 \end{pmatrix}, z\begin{pmatrix} w_1 \\ w_2 \end{pmatrix}-\begin{pmatrix} x_1 \\ x_2 \end{pmatrix}\right): w_2=-\frac{3}{2}w_1, x_1=-w_1, \forall\begin{pmatrix} w_1 \\ w_2 \end{pmatrix}\in D(L)\right\}. \qquad (14)$$

Therefore, we get $(z-\mathrm{A})w=0 \Leftrightarrow \begin{pmatrix} (z+1)w_1 \\ -\frac{3}{2}zw_1-x_2 \end{pmatrix}=\begin{pmatrix} 0 \\ 0 \end{pmatrix}$. Clearly, we get $z=-1$ and $w=\begin{pmatrix} w_1 \\ -\frac{3}{2}w_1 \end{pmatrix}$ where $w_1\neq 0$. Consequently, a point spectrum of A is $\sigma_p(\mathrm{A})=\{-1\}$. Thus, eigenvalues of relation A is $z=-1$, and eigenvectors of relation A is $\left\{\begin{pmatrix} w_1 \\ -\frac{3}{2}w_1 \end{pmatrix}: w_1\neq 0\right\}$.

Let $z\in\mathbb{C}$, we get

$$\left\|\begin{pmatrix} (z+1)w_1 \\ -\frac{3}{2}zw_1-x_2 \end{pmatrix}\right\|\geq |z|\left\|\begin{pmatrix} w_1 \\ -\frac{3}{2}w_1 \end{pmatrix}\right\|-1\left\|\begin{pmatrix} -w_1 \\ x_2 \end{pmatrix}\right\|. \qquad (15)$$

$$\leq (|z|-1)\left\|\begin{pmatrix} w_1 \\ -\frac{3}{2}w_1 \end{pmatrix}\right\|.$$

We can notfind $C(z) > 0$ such that $\left\|\begin{pmatrix}(z+1)w_1\\ -\frac{3}{2}zw_1 - x_2\end{pmatrix}\right\| \geq (|z|-1)\left\|\begin{pmatrix}w_1\\ -\frac{3}{2}w_1\end{pmatrix}\right\|$.Consequently, the resolvent set of A is the set $\rho(\mathrm{A}) = \varnothing$ and spectrum of A is $\sigma(A) = \{z : z \in \mathbb{C}\}$. A point spectrum of A is $\sigma_p(\mathrm{A}) = \{-1\} \subset \sigma(\mathrm{A})$.

## 4. Conclusion

An eigenvalues and eigenvectors of abstract Cauchy problems can be determined by linear relations. A relation A on H is a self-adjoint. The following are the properties of spectral theory of SALRon H. If $w$ is an eigenvector of A corresponding to the eigenvalue $z$ and $\beta$ is an non zero scalar, then $\beta w$ is also an eigenvector of A corresponding to the same eigenvalue. If $w$ is an eigenvector of A then $w$ cannot correspond to more than one eigenvalue of A. Consequently, eigenvectors $w_1$ and $w_2$ belonging to the two different eigenvalues of $z_1$ and $z_2$ a SALR are orthogonal.Let $\mathrm{A} \in LR(\mathrm{H})$ is a SALR that have an eigenvalue $z$, then an eigenspaces A of are pairwise orthogonal.

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# Spectral theory for self-adjoint linear relation (SALR) on a Hilbert space and its application in homogenous abstract cauchy problem

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