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Integral Transform of three Parameters with its Applications

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Abstract

In this paper, we will present a new definition for three-parameters integral transformation, in addition to some basic properties and theorems for this transform, the main aim of presetting this transform is to solve some life-medical problems. The three parameters play an essential role in simplifying the algebraic operations for the data given in the problem. This was explained from through some examples and applications.

Keywords: *NO transform, Fourier transform, Laplace transform, SEE transform complex SEE transform, Sadik transform, Complex Sadik transform, SEJI transform, Novel Transform, Ordinary differential equations.*

1-Introduction

Due to the importance of solutions of differential and integral equations and their connection to real-life problems, many researchers seek to invent new, simpler methods that are easier than the ones before them, and their primary goal is to transform these difficult problems into algebraic equations that are easier and simpler than they are, and this is through integral transformations, starting with the Laplace transform.

After the Laplace transform, many integral transforms appeared, such as the Sumudu, El-Zaki, Aboodh, Millen, Mahjoub, Muhannad, Gupta, Emad-Sara, Emad-Faleh transform, the SEE transform, the complex SEE transform, Al Zughir transform, Al Tememe, Shaaban, Al-Jaafari, Sadiq, and complex Sadiq transforms. There are many others, and each transform differs from the other, either in terms of interval, the transform kernel, or the number of parameters present in the kernel. Certainly, there is no advantage that prefers one transform over another, except in solving a problem or a special application.[1-31].

For example, the SEE transform [16], through this transform, an image was encrypted and results were obtained with mathematical operations easier than before. The SEJI transform [32] also used this transform with fuzzy in encoding images, and each transform solves an important problem in applications and general life.

A new NO integral transform will be presented by Noor k.Sallman and denoted by $NO\{\cdot\}$.

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2. Definitions and Properties

Definition (2.1): The new NO integral transform of the function $g(t)$ on the interval $(0,\infty)$ is defined as:

$$NO\{g(t)\} = N(u,v,s;\beta) = \left(\frac{v}{s}\right)^{\beta} \int_{0}^{\infty} e^{-ut}\, g(st)dt,$$

Where β ∈ Z, and u,v,s>0 are parameters.Type equation here.

Definition (2.2): The inverse of The NO transform $N^{-1}\{\cdot\}$ is defined as:

$$N^{-1}\{N(u,v,s;\beta)\} = g(t) = \frac{1}{2\pi i} \int_{a+ib}^{a-ib} \left(\frac{v}{s}\right)^{-\beta} N(u,v,s)\, e^{ut}\, duvs\,,$$

In general, $t = a + ib$ with a and b being real numbers.

The integral converges when $Re\,[t] = a > 0$ and if $a < 0$, $N(u,v,s) = 0$ and $i \in \mathbb{R}$.

Property (2.1): (Linearly Property)

Let $g_1(t)$ and $g_2(t)$ have NO transform $N_1(u,v,s)$ and $N_2(u,v,s)$ then the NO transform of $NO\{\varphi g_1(t) \pm \omega g_2(t)\} = \varphi NO\{g_1(t)\} \pm \omega NO\{g_2(t)\}$.

Where φ and ω are constants.

3. NO Transform of Elementary Functions

This part presents the most fundamental functions of the NO transform with their proofs.

i. If $g(t) = 1$ then by definition of NO transform we get: $NO\{g(t)\} = N(1) = \left(\frac{v}{s}\right)^{\beta} \int_0^{\infty} e^{-ut}\, dt,$

$= \left(\frac{v}{s}\right)^{\beta} \frac{1}{-u}(e^{-\infty} - e^{0})$

$= \left(\frac{v}{s}\right)^{\beta} \frac{1}{u}$.

ii. If $g(t) = t^n, n = 1,2,3, \ldots$ then by definition of Noor transform we get:

$NO\{g(t)\} = N(t^n) = \left(\frac{v}{s}\right)^{\beta} \int_0^{\infty} e^{-ut}\, t^n\, dt,$

$= \left(\frac{v}{s}\right)^{\beta} s^n \int_0^{\infty} e^{-z}\, (\frac{z}{u})^n \frac{dz}{u}\, , z = ut,$

$= \left(\frac{v}{s}\right)^{\beta} \frac{s^n}{u^{n+1}} \int_0^{\infty} e^{-z}\, z^n\, dz,$

$= \frac{v^{\beta} n!}{s^{\beta-n}\, u^{n+1}}$.

iii. If $g(t) = e^t$ then by definition of NO transform we get:

$NO\{g(t)\} = N(e^t) = \left(\frac{v}{s}\right)^{\beta} \int_0^{\infty} e^{-ut}\, e^{st}\, dt,$

$= \left(\frac{v}{s}\right)^{\beta} \int_0^{\infty} e^{-(u-s)t}\, dt,$

$= \left(\frac{v}{s}\right)^{\beta} \frac{1}{-(u-s)} (e^{-\infty} - e^{0}),$
$= \frac{v^{\beta}}{s^{\beta}(u-s)} .$

iv.If $g(t) = \sin t$ then by definition of NO transform we get:

$$NO\{g(t)\} = N(\sin t) = \left(\frac{v}{s}\right)^{\beta} \int_0^{\infty} e^{-ut} \sin(st)\, dt,$$
$$= \left(\frac{v}{s}\right)^{\beta} \int_0^{\infty} e^{-ut} \left[\frac{e^{ist}-e^{-ist}}{2i}\right] dt,$$
$$= \left(\frac{v}{s}\right)^{\beta} \frac{1}{2i} [\int_0^{\infty} e^{-(u-is)t} dt - \int_0^{\infty} e^{-(u+is)t} dt],$$
$$= \left(\frac{v}{s}\right)^{\beta} \frac{1}{2i} [\frac{1}{-(u-is)} (e^{-\infty} - e^{0}) - \left(\frac{1}{-(u+is)} (e^{-\infty} - e^{0})\right)],$$
$$= \left(\frac{v}{s}\right)^{\beta} \frac{1}{2i} (\frac{2is}{u^2+s^2}) .$$
$$= \frac{v^{\beta}}{s^{\beta-1}(u^2+s^2)} .$$

v.If $g(t) = \cos t$ then by definition of NO transform we get:

$$NO\{g(t)\} = N(\cos t) = \left(\frac{v}{s}\right)^{\beta} \int_0^{\infty} e^{-ut} \cos(st)\, dt,$$
$$= \left(\frac{v}{s}\right)^{\beta} \int_0^{\infty} e^{-ut} \left[\frac{e^{ist}+e^{-ist}}{2}\right] dt,$$
$$= \left(\frac{v}{s}\right)^{\beta} \frac{1}{2} [\int_0^{\infty} e^{-(u-is)t} dt - \int_0^{\infty} e^{-(u+is)t} dt],$$
$$= \left(\frac{v}{s}\right)^{\beta} \frac{1}{2} [\frac{1}{-(u-is)} (e^{-\infty} - e^{0}) + \left(\frac{1}{-(u+is)} (e^{-\infty} - e^{0})\right)],$$
$$= \left(\frac{v}{s}\right)^{\beta} \frac{1}{2} (\frac{2u}{u^2+s^2}),$$
$$= \frac{v^{\beta} u}{s^{\beta}(u^2+s^2)} .$$

vi.If $g(t) = \sinh t$ then by definition of NO transform we get:

$$NO\{g(t)\} = N(\sinh t) = \left(\frac{v}{s}\right)^{\beta} \int_0^{\infty} e^{-ut} \sinh(st)\, dt,$$
$$= \left(\frac{v}{s}\right)^{\beta} \int_0^{\infty} e^{-ut} \left[\frac{e^{st}-e^{-st}}{2}\right] dt,$$
$$= \left(\frac{v}{s}\right)^{\beta} \frac{1}{2} [\int_0^{\infty} e^{-(u-s)t} dt - \int_0^{\infty} e^{-(u+s)t} dt],$$
$$= \left(\frac{v}{s}\right)^{\beta} \frac{1}{2} [\frac{1}{-(u-s)} (e^{-\infty} - e^{0}) - \left(\frac{1}{-(u+s)} (e^{-\infty} - e^{0})\right)],$$
$$= \left(\frac{v}{s}\right)^{\beta} \frac{1}{2} (\frac{2s}{u^2-s^2}),$$
$$= \frac{v^{\beta}}{s^{\beta-1}(u^2-s^2)} .$$

vii.If $g(t) = \cosh t$ then by definition of NO transform we get:

$NO\{g(t)\} = N(\cosh t) = \left(\frac{v}{s}\right)^{\beta} \int_0^{\infty} e^{-ut} \cosh(st)\, dt,$

$= \left(\frac{v}{s}\right)^{\beta} \int_0^{\infty} e^{-ut} \left[\frac{e^{st}+e^{-st}}{2}\right] dt,$

$= \left(\frac{v}{s}\right)^{\beta} \frac{1}{2} [\int_0^{\infty} e^{-(u-s)t} dt + \int_0^{\infty} e^{-(u+s)t} dt],$

$= \left(\frac{v}{s}\right)^{\beta} \frac{1}{2} [\frac{1}{-(u-s)} (e^{-\infty} - e^{0}) + \left(\frac{1}{-(u+s)} (e^{-\infty} - e^{0})\right)],$

$= \left(\frac{v}{s}\right)^{\beta} \frac{1}{2} (\frac{2u}{u^2-s^2}),$

$= \frac{v^{\beta}\, u}{s^{\beta}(u^2-s^2)}.$

4. Inverse NO Transform of Basic functions

The inverse NO transform of the function $G(u,v,s)$ is denoted by $N^{-1}\{G(u,v.s)\}$ or $g(t)$. If we write $N\{g(t)\} = G(u,v,s)$, then $N^{-1}\{G(u,v.s)\} = g(t)$, where N^{-1} is called the inverse Noor transform(NO) operator. The inverse Noor transform (NO) of some elementary functions are given below

- $N^{-1}\left\{\left(\frac{v}{s}\right)^{\beta} \frac{1}{u}\right\} = 1$
- $N^{-1}\left\{\frac{v^{\beta} n!}{s^{\beta-n}\, u^{n+1}}\right\} = t^{n}$,$n = 1,2,3 \cdots$.
- $N^{-1}\left\{\frac{v^{\beta}}{s^{\beta}(u-s)}\right\} = e^{t}$
- $N^{-1}\left\{\frac{v^{\beta}}{s^{\beta-1}(u^2+s^2)}\right\} = \sin t$
- $N^{-1}\left\{\frac{v^{\beta} u}{s^{\beta}(u^2+s^2)}\right\} = \cos t$
- $N^{-1}\left\{\frac{v^{\beta}}{s^{\beta-1}(u^2-s^2)}\right\} = \sinh t$
- $N^{-1}\left\{\frac{v^{\beta}\, u}{s^{\beta}(u^2-s^2)}\right\} = \cosh t$

4. NO Transform of Derivatives

The NO transform for derivatives is presented in this part:

Theorem (4.1)

Let $N(u,v,s)$ is the NO transform of $[NO\{g(t)\} = N(u,v,s)]$,

I. $NO\{g'(t)\} = uNO\{g(t)\} - \left(\frac{v}{s}\right)^{\beta} g(0),$

Proof:

$NO\{g'(t)\} = \left(\frac{v}{s}\right)^{\beta} \int_0^{\infty} e^{-ut}\, g'(st)\, dt$.

Integrating by parts we get:

$NO\{g'(t)\} = \left(\frac{v}{s}\right)^{\beta} ([e^{-ut}\, g(st)]_0^{\infty} - \int_0^{\infty} -u\, e^{-ut}\, g(st) dt),$

$= \left(\frac{v}{s}\right)^{\beta} [\left(e^{-\infty} g(\infty) - e^{0} g(0)\right) + u \int_0^{\infty} e^{-ut} \; g(st)dt],$

$= \left(\frac{v}{s}\right)^{\beta} u \int_0^{\infty} e^{-ut} \; g(st)dt - \left(\frac{v}{s}\right)^{\beta} g(0),$

$= u\, NO\{g(t)\} - \left(\frac{v}{s}\right)^{\beta} \; g(0),$

II.NO$\{g''(t)\} = u^2 NO\{g(t)\} - \left(\frac{v}{s}\right)^{\beta} (u\, g(0) + g'(0))$

Proof: By I and Integrating by parts:

$= u\, NO\{g'(t)\} - \left(\frac{v}{s}\right)^{\beta} \; g'(0),$

$= u\left[u\, NO\{g(t)\} - \left(\frac{v}{s}\right)^{\beta} \; g(0)\right] - \left(\frac{v}{s}\right)^{\beta} \; g(0),$

$= u^2 NO\{g(t)\} - \left(\frac{v}{s}\right)^{\beta} \; u\, g(0) - \left(\frac{v}{s}\right)^{\beta} \; g'(0),$

$= u^2 NO\{g(t)\} - \left(\frac{v}{s}\right)^{\beta} (u\, g(0) + g'(0)).$

III.$NO\{g'''(t)\} = u^3 NO\{g(t)\} - \left(\frac{v}{s}\right)^{\beta} (g''(0) + u\, g'(0) + u^2\, g(0))$

Proof: By I, II and Integrating by parts:

$NO\{g'''(t)\} = u^2 NO\{g'(t)\} - \left(\frac{v}{s}\right)^{\beta} (u\, g'(0) + g''(0)),$

$=u^2 \left[u\, NO\{g(t)\} - \left(\frac{v}{s}\right)^{\beta} \; g(0)\right] - \left(\frac{v}{s}\right)^{\beta} (u\, g'(0) + g''(0)),$

$= u^3 NO\{g(t)\} - \left(\frac{v}{s}\right)^{\beta} (g''(0) + u\, g'(0) + u^2\, g(0)).$

IV.$NO\{g^{(n)}(t)\} = u^n NO\{g(t)\} + \left(\frac{v}{s}\right)^{\beta} \sum_{i=0}^{n-1} u^{n-i-1} \; g^{(i)}(0)$.

Where $n \in \mathbb{N}$.

5- Examples

In this part of the paper, we presented two examples to illustrate the definition and theorems of this transforms.

Example 1: consider the first order differential equation

$g' + g = 0$, where $g(0) = 1$.

Solution: by NO Transform we get:

$uN\{g(t)\} - \left(\frac{v}{s}\right)^{\beta} \; g(0) + N\{g(t)\} = 0$,

$NO\{g(t)\}(u + 1) = \left(\frac{v}{s}\right)^{\beta}$,

$NO\{g(t)\} = G(t) = \left(\frac{v}{s}\right)^{\beta} \frac{1}{(u+1)}$

Taking inverse NO Transform, we get the exact solution

$g(t) = e^{-t}$.

Example 2: Consider The Second Order Differential Equation

$g'' - 3g' + 2g = 0$, where $g(0) = 1$, $g'(0) = 4$

Solution: by NO Transform we get:

$$u^2 NO\{g(t)\} - \left(\frac{v}{s}\right)^\beta \left(u\, g(0) + g'(0)\right) - 3\left(u\, NO\{g(t)\} - \left(\frac{v}{s}\right)^\beta g(0)\right) + 2NO\{g(t)\} = 0$$

$$NO\{g(t)\}(u^2 - 3u + 2) = \left(\frac{v}{s}\right)^\beta (u + 4) - 3\frac{v^\beta}{s^\beta},$$

$$NO\{g(t)\} = \left(\frac{v}{s}\right)^\beta \frac{u+1}{(u^2-3u+2)},$$

$$NO\{g(t)\} = \left(\frac{v}{s}\right)^\beta \frac{u+1}{(u-2)(u-1)},$$

Or

$$NO\{g(t)\} = G(t) = 3\left(\frac{v}{s}\right)^\beta \frac{1}{u-2} - 2\left(\frac{v}{s}\right)^\beta \frac{1}{u-1}$$

Taking inverse NO Transform, we have the exact solution

$g(t) = 3e^{2t} - 2e^t$.

6- Applications of NO Transform

In this section three applications were presented including physical, life and medical applications, due to their importance.

Applications 1

A particle falls in a vertical line under constant gravity and the force of air resistance to its motion is proportional to its velocity. The equation of motion of the particle is $g'(t) = w - k\, g$ where g is the velocity when the particle has fallen a distance y in time t from rest and $k\, g$ is the air resistance [29]. We will apply the NO Transform to solve the differential equation of motion of the particle.

Solution: The differential equation of motion of the particle is given by

$g'(t) = w - k\, g(t)$.

Applying NO Transform, we have:

$$u\, NO\{g(t)\} - \left(\frac{v}{s}\right)^\beta g(0) = \frac{w\, v^\beta}{u\, s^\beta} - k\, NO\{g(t)\}$$

At $t = 0$, $g(0) = 0$, therefore, solving and rearranging the equation, we have

$$NO\{g(t)\} = \frac{w\, v^\beta}{s^\beta\, u(u+k)},$$

or

$$NO\{g(t)\} = g(t) = \frac{w}{k}\left(\frac{v^\beta}{u\, s^\beta} - \frac{v^\beta}{s^\beta(u+k)}\right),$$

Taking inverse NO Transform, we have:

$g(t) = \frac{w}{k}(1 - e^{-kt})$.

Application (2) (Blood Glucose Concentration)

During continuous intravenous glucose injection, the concentration of glucose in the blood is $G(t)$ exceeding the baseline value at the start of the infusion. The function $G(t)$ satisfies the initial value problem (I.V.P.), [1]

$G'(t) + kG(t) = \frac{\alpha}{\gamma}$, where $t > 0$ and, $G(0) = 0$.

The variables in this equation are k, α, and γ, which respectively represent the constant velocity of elimination, the rate of infusion, and the volume in which glucose is distributed.

Solution: By NO transform will be utilized to assess the concentration of glucose present in the bloodstream

$$u\, NO\{g(t)\} - \left(\frac{v}{s}\right)^{\beta} g(0) + kNO\{g(t)\} = \frac{\alpha}{\gamma}\, NO\{1\}$$
$$NO\{g(t)\}(u+k) = \frac{\alpha}{\gamma}\frac{v^{\beta}}{u\, s^{\beta}},$$
$$NO\{g(t)\} = \frac{\alpha}{\gamma}\left(\frac{v}{s}\right)^{\beta}\left(\frac{1}{u(u+k)}\right).$$

Or $NO\{g(t)\} = G(t) = \frac{\alpha}{\gamma\, k}\left(\frac{v^{\beta}}{u\, s^{\beta}} - \frac{v^{\beta}}{s^{\beta}(u+k)}\right)$.

Taking inverse NO Transform, we have :

$$g(t) = \frac{\alpha}{\gamma\, k}(1 - e^{-kt}).$$

Application (3): (Aorta Pressure)

The heart's contraction facilitates the transportation of blood into the aorta. The initial value problem denoted by Debnath and Bhatta [1] is concerned with the aortic pressure function $p(t)$ as: $p'(t) + \frac{c}{k}\, p(t) = cAsin(wt),\ \ p(0) = p_0$, c, k, A and p_0 are constants.

Solution: by NO transform is utilized to derive the pressure in the aorta.

$$u\, NO\{p(t)\} - \left(\frac{v}{s}\right)^{\beta} p(0) + \frac{c}{k} N\{\, p(t)\} = cA\, N\{sin(wt)\},$$
$$NO\{p(t)\}\left(u + \frac{c}{k}\right) - \left(\frac{v}{s}\right)^{\beta} p_0 = cA\frac{v^{\beta} s}{s^{\beta}(u^2+(sw)^2)},$$
$$NO\{p(t)\} = \frac{cA\, v^{\beta}\, s^{\beta+1} + p_0\, v^{\beta}\, s^{\beta}(u^2+(sw)^2)}{s^{2\beta}(u^2+(sw)^2)(u+\frac{c}{k})},$$
$$NO\{p(t)\} = \left(\frac{v}{s}\right)^{\beta}\frac{p_0}{u+\frac{c}{k}} + \left(\frac{v}{s}\right)^{\beta}\left[\frac{cAs}{(u^2+(sw)^2)\left(u+\frac{c}{k}\right)}\right],$$

Or

$$NO\{p(t)\} = \left(\frac{v}{s}\right)^{\beta}\frac{p_0}{u+\frac{c}{k}} + \frac{cAs}{(\frac{c}{k})^2+(sw)^2}\left[\left(\frac{v}{s}\right)^{\beta}\frac{1}{u+\frac{c}{k}} - \left(\frac{v}{s}\right)^{\beta}\frac{u}{(u^2+(sw)^2)} + \left(\frac{v}{s}\right)^{\beta}\frac{\frac{c}{k}}{(u^2+(sw)^2)}\right.$$

Taking inverse NO Transform, we have the exact solution of aorta pressure

$$p(t) = p_0\, e^{-\frac{c}{k}t} + \frac{cAs}{(\frac{c}{k})^2+(sw)^2}\left[e^{-\frac{c}{k}t} - \cos(wt) + \sin(wt)\right].$$

7-Conclusion

In this work, a new integral transform with three-parameters is presented, the NO transform with its basic properties, its application to fundamental functions and their derivatives, and its application to three real-life problems: in physics, the effect of constant gravity on a body, and in medicine, blood glucose concentration and aortic pressure. The application of the NO transform has proven its simplicity and ability to solve algebraic problems, giving this integral transform great usability in many scientific fields.

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