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ON NOVEL INTEGRAL TRANSFORM: ROHIT TRANSFORM AND ITS APPLICATION TO BOUNDARY VALUE PROBLEMS

Rohit Gupta†

[1]Lecturer of Physics, Dept. of Applied Sciences, Yogananda College of Engineering and Technology, Jammu.

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Corresponding Author:
† Rohit Gupta

E-mail: guptarohit565@gmail.com
Contact: +91-9797653429

† Lecturer of Physics, Dept. of Applied Sciences, Yogananda College of Engineering and Technology, Jammu.

ABSTRACT

In this paper, a novel integral transform named Rohit Transform (RT) is proposed. The operational properties of Rohit Transform (RT) are discussed. The Rohit Transform (RT) of elementary functions and some of the derivatives of a function are obtained. The boundary value problems in Science and Engineering are analyzed by the application of Rohit Transform (RT).

Index Terms: Rohit Transform (RT), Boundary Value Problems.

INTRODUCTION

There is a number of integral transforms such as Laplace Transform [1], [2], Elzaki Transform [3], Sadik Transform [4], Kamal Transform [5], Aboodh Transform [6], Mohand Transform [7], Mahgoub Transform [8], Yang Transform [9], Gupta Transform [10], Dinesh Verma Transform [11] etc. These Transforms are widely used for analyzing the boundary value problems described by ordinary differential equations in Science and Engineering like unidirectional heat flow problems [12], [13], [14], [15], network circuit analysis [16], [17], [18], [19], [20], quantum mechanical problems [21], [22], [23], [24], analysis of damped harmonic oscillator and moving coil galvanometer [25], [26], analysis of unidirectional laminar flow [27], conduction of heat through fins [28], [29], simultaneous differential equations [1], [2], [30] and etc. In this paper, the author Rohit Gupta proposed a novel integral transform named Rohit Transform (RT) and applied it for analyzing some boundary value problems described by linear ordinary differential equations with constant coefficients in Science and Engineering.

I. DEFINITION OF ROHIT TRANSFORM (RT)

Let g(y) is a well-defined function of real numbers y ≥ 0. The Rohit Transform (RT) of g(y), denoted by $G(r)$ or $R\{g(y)\}$, is defined as

$R\{g(y)\} = r^3 \int_0^\infty e^{-ry} g(y)\,dy = G(r)$, provided that the integral is convergent, where r may be a real or complex parameter and R is the Rohit Transform (RT) operator.

II. ROHIT TRANSFORM (RT) OF ELEMENTARY FUNCTIONS

According to the definition of Rohit Transform (RT), $R\{g(y)\} = r^3 \int_0^\infty e^{-ry} g(y)\,dy$, then

1. $R\{1\} = r^3 \int_0^\infty e^{-ry}\,dy$

$$= -r^2(e^{-\infty} - e^{-0})$$
$$= -r^2(0-1)$$
$$= r^2$$

Hence $R\{1\} = r^2$

2. $R\{y^n\} = r^3 \int_0^\infty e^{-ry} y^n\,dy$

$$= r^3 \int_0^\infty e^{-z} \left(\frac{z}{r}\right)^n \frac{dz}{r} \quad , z = ry$$
$$= \frac{r^2}{r^n} \int_0^\infty e^{-z} (z)^n dz$$

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Applying the definition of the gamma function,

$R\{y^n\} = \frac{r^2}{r^n}\Gamma(n+1)$

$= \frac{r^2}{r^n}n!$

$= \frac{n!}{r^{n-2}}$

Hence $R\{y^n\} = \frac{n!}{r^{n-2}}$

3. $R\{sinby\} = r^3\int_0^\infty e^{-ry}\, sinby\, dy$

$= r^3\int_0^\infty e^{-ry}\left(\frac{e^{iby} - e^{-iby}}{2i}\right)dy$

$= r^3\int_0^\infty \left(\frac{e^{-(r-ib)y} - e^{-(r+ib)y}}{2i}\right)dy$

$= -\frac{r^3}{2i(r-ib)}\left(e^{-\infty} - e^{-0}\right) + \frac{r^3}{2i(r+ib)}\left(e^{-\infty} - e^{-0}\right)$

$= \frac{r^3}{2i(r-ib)} - \frac{r^3}{2i(r+ib)}$

$= \frac{b\,r^3}{r^2+b^2}$

Hence $R\{sinby\} = \frac{b\,r^3}{r^2+b^2}$

4. $R\{sinhby\} = r^3\int_0^\infty e^{-ry}\, sinhby\, dy$

$= r^3\int_0^\infty e^{-ry}\left(\frac{e^{by} - e^{-by}}{2}\right)dy$

$= r^3\int_0^\infty \left(\frac{e^{-(r-b)y} - e^{-(r+b)y}}{2}\right)dy$

$= -\frac{r^3}{2(r-b)}\left(e^{-\infty} - e^{-0}\right) + \frac{r^3}{2(r+b)}\left(e^{-\infty} - e^{-0}\right)$

$= \frac{r^3}{2(r-b)} - \frac{r^3}{2(r+b)}$

$= \frac{b\,r^3}{r^2-b^2}$

Hence $R\{sinhby\} = \frac{b\,r^3}{r^2-b^2}$

5. $R\{cosby\} = r^3\int_0^\infty e^{-ry}\, cosby\, dy$

$= r^3\int_0^\infty e^{-ry}\left(\frac{e^{iby} + e^{-iby}}{2}\right)dy$

$= r^3\int_0^\infty \left(\frac{e^{-(r-ib)y} + e^{-(r+ib)y}}{2}\right)dy$

$= -\frac{r^3}{2(r-ib)}\left(e^{-\infty} - e^{-0}\right) - \frac{r^3}{2(r+ib)}\left(e^{-\infty} - e^{-0}\right)$

$= \frac{r^3}{2(r-ib)} + \frac{r^3}{2(r+ib)}$

$= \frac{r^4}{r^2+b^2}$

Hence $R\{cosby\} = \frac{r^4}{r^2+b^2}$

6. $R\{coshby\} = r^3\int_0^\infty e^{-ry}\, coshby\, dy$

$= r^3\int_0^\infty e^{-ry}\left(\frac{e^{by} + e^{-by}}{2}\right)dy$

$= r^3\int_0^\infty \left(\frac{e^{-(r-b)y} + e^{-(r+b)y}}{2}\right)dy$

$= -\frac{r^3}{2(r-b)}\left(e^{-\infty} - e^{-0}\right) - \frac{r^3}{2(r+b)}\left(e^{-\infty} - e^{-0}\right)$

$= \frac{r^3}{2(r-b)} + \frac{r^3}{2(r+b)}$

$= \frac{r^4}{r^2-b^2}$

Hence $R\{coshby\} = \frac{r^4}{r^2-b^2}$

7. $R\{e^{by}\} = r^3\int_0^\infty e^{-ry}\, e^{by}\, dy$

$= r^3\int_0^\infty\left(e^{-(r-b)y}\right)dy$

$= -\frac{r^3}{(r-b)}\left(e^{-\infty} - e^{-0}\right)$

$= \frac{r^3}{(r-b)}$

Hence $R\{e^{by}\} = \frac{r^3}{r-b}$

8. $R\{\delta(y-b)\} = r^3\int_0^\infty e^{-ry}\,\delta(y-b)\,dy$

Since the unit step function $\delta(y-b), b \geq 0,$ is defined [1] as

$\delta(y-b) = 0$ when $y < b$ and

$\delta(y-b) = 1$ when $y \geq b$, therefore, the above integral can be rewritten as

$R\{\delta(y-b)\} = r^3\int_b^\infty e^{-ry}\,dy$

$= -\frac{r^3}{r}\left(e^{-\infty} - e^{-br}\right)$

$= r^2 e^{-br}$

Hence $R\{\delta(y-b)\} = r^2 e^{-br}$

Hence we found that the Rohit Transform (RT) of some elementary functions are

- $R\{1\} = r^2, \quad r > 0$
- $R\{y^n\} = \frac{n!}{r^{n-2}}$, where $n = 0,1,2,3 \ldots \ldots$
- $R\{e^{by}\} = \frac{r^3}{r-b}, \quad r > b$
- $R\{sinby\} = \frac{b\,r^3}{r^2+b^2}, \quad r > 0$
- $R\{sinhby\} = \frac{b\,r^3}{r^2-b^2}, \quad r > |b|$
- $R\{cosby\} = \frac{r^4}{r^2+b^2}, \quad r > 0$
- $R\{coshby\} = \frac{r^4}{r^2-b^2}, \quad r > |b|$
- $R\{\delta(y-b)\} = r^2 e^{-br}$
- $R\{\delta(y)\} = r^2$

III. INVERSE ROHIT TRANSFORM (RT) OF ELEMENTARY FUNCTIONS

The inverse Rohit Transform (RT) of the function G(r) is denoted by R^{-1}\{G (r)\} or g (y).

If we write R \{g (y)\} = G (r), then R^{-1}\{G (r)\} = g (y), where R^{-1} is called the inverse Rohit Transform (RT) operator.

The Inverse Rohit Transform (RT) of some elementary functions are given below

- $R^{-1}\{1/r^n\} = \frac{y^{n+2}}{(n+2)!}$
- $R^{-1}\left\{\frac{r^3}{r-b}\right\} = e^{by}$
- $R^{-1}\left\{\frac{r^3}{r^2+b^2}\right\} = \frac{1}{b}sinby$
- $R^{-1}\left\{\frac{r^3}{r^2-b^2}\right\} = \frac{1}{b}sinhby$
- $R^{-1}\left\{\frac{r^4}{r^2+b^2}\right\} = cosby$
- $R^{-1}\left\{\frac{r^4}{r^2-b^2}\right\} = coshby$

IV. ROHIT TRANSFORM (RT) OF DERIVATIVES

Let g(y) is continuous function and is piecewise continuous on any interval, then the Rohit Transform (RT) of first derivative of g(y) i.e. $R\{g'(y)\}$ is given by

$R\{g'(y)\} = r^3\int_0^\infty e^{-ry}\, g'(y)dy$

Integrating by parts and applying limits, we get

$R\{g'(y)\}$

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$=$
$r^3\{-g(0) - \int_0^\infty -re^{-ry}\, g(y)dy\} =$
$r^3\{-g(0) + r\int_0^\infty e^{-ry}\, g(y)\, dy\}$

$= r^3\{-g(0) + rR\{g(y)\}\}$
$= rG(r) - r^3 g(0)$
Hence
$R\{g'(y)\} = rG(r) - r^3 g(0)$
Since
$R\{g'(y)\} = rR\{g(y)\} - r^3 g(0),$
Therefore, on replacing g(y) by $g'(y)$ and $g'(y)$ by $g''(y)$, we have
$R\{g''(y)\} = rR\{g'(y)\} - r^3 g'(0)$
$= r\{rR\{g(y)\} - r^3 g(0)\} - r^3 g'(0)$
$= r^2 R\{g(y)\} - r^4 g(0) - r^3 g'(0)$
$= r^2 G(r) - r^4 g(0) - r^3 g'(0)$
Hence
$R\{g''(y)\} = r^2 G(r) - r^4 g(0) - r^3 g'(0)$
Similarly,
$R\{g'''(y)\} = r^3 G(r) - r^5 g(0) - r^4 g'(0) - r^3 g''(0)$ And so on.
Also we can prove the following Rohit Transform (RT):
$R\{yg(y)\} = \frac{3}{r} R\{g(y)\} - \frac{d}{dr} R\{g(y)\},$
$R\{yg'(y)\} = 2R\{g(y)\} - r\frac{d}{dr} R\{g(y)\},$
$R\{yg''(y)\} = rR\{g(y)\} + r^3 g(0) - r^2 \frac{d}{dr} R\{g(y)\}$

V. APPLICATIONS OF ROHIT TRANSFORM (RT)

APPLICATION 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 $v'(t) = g - kv$, where v is the velocity when the particle has fallen a distance y in time t from rest and kv is the air resistance [10]. We will apply the Rohit Transform (RT) to solve the equation of motion of the particle.
Solution:
The equation of motion of the particle is given by
$v'(t) = g - kv(t)$
Applying Rohit Transform (RT), we have
$r\,G(r) - r^3 v(0) = g\,r^2 - kG(r)$
At t = 0, $v(0) = 0$, therefore, solving and rearranging the equation, we have
$G(r) = \frac{g\,r^2}{r+k}$
Or
$G(r) = \frac{g}{k}[\,r^2 - \frac{r^3}{r+k}]$
Taking inverse Rohit Transform (RT), we have
$v(t) = \frac{g}{k}[1 - e^{-kt}]$

APPLICATION 2:
RL series circuit: Let $I(t)$ be the current flowing in the RL series circuit with voltage E, at any time t, then by voltage law [18] [31], [32], we have
$L\,I'(t) + RI(t) = E$
Or
$I'(t) + \frac{R}{L} I(t) = \frac{E}{L}$
We will apply the Rohit Transform (RT) to obtain the current in the circuit at instant t.
Solution:
Applying Rohit Transform (RT), we have
$rG(r) - r^3 I(0) + \frac{R}{L} G(r) = \frac{E}{L}\, r^2$
At t = 0, $I(0) = 0$, therefore, solving and rearranging the equation, we have
$G(r) = \frac{E}{L} \frac{r^2}{r + \frac{R}{L}}$
Or
$G(r) = \frac{E}{R}[\,r^2 - \frac{r^3}{r+\frac{R}{L}}]$
Taking inverse Rohit Transform (RT), we have
$I(t) = \frac{E}{R}[1 - e^{-\frac{R}{L}t}]$

APPLICATION 3:
Simple Harmonic Motion: Consider a particle of mass m executing simple harmonic motion. If x is the displacement of the particle from the mean position at any instant t, the differential equation describing the motion of the particle is given by [2]
$x''(t) + w^2 x = 0, w^2 = k/m.$
We will apply the Rohit Transform (RT) to find the displacement of the particle at any instant t.
Assume that at t = 0, $x(0) = 0$ and $x'(0) = 1$.
Solution:
$x''(t) + w^2 x = 0$
Applying the Rohit Transform (RT), we have
$r^2 G(r) - r^4 x(0) - r^3 x'(0) + w^2 G(r) = 0$
At t = 0, $x(0) = 0$ and $x'(0) = 1$, solving and rearranging the equation, we have
$G(r) = \frac{r^3}{r^2 + w^2}$
Taking inverse Rohit Transform (RT) and solving, we have
$x(t) = \frac{1}{w}\sin wt$
Or
$x(t) = \sqrt{\frac{m}{k}} \sin \sqrt{\frac{m}{k}}\, t$

APPLICATION 4:
Uranium disintegrates at a rate proportional to the amount present at any instant [11]. We will apply the Rohit Transform (RT) to find the amount of uranium at any instant t.
Solution:
Let 'N' be the amount of uranium initially at t = 0 and n be the amount of uranium at any instant t, then

$n'(t) = -\lambda n$

Applying Rohit Transform (RT), we have

$r\,G(r) - r^3 n(0) = -\lambda G(r)$

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

$$G(r) = \frac{N\,r^3}{r+\lambda}$$

Taking inverse Rohit Transform (RT), we have

$$n(t) = Ne^{-\lambda t}$$

APPLICATION 5:

The rate of decrease in temperature of the body is proportional to the difference between the temperature of the body and that of the medium [10]. We will apply the Rohit Transform (RT) to find the temperature of the body at any instant t.

Solution:

Let T_1 be the temperature of the body initially, 'T' be the temperature of the body at any instant t and T_o be the temperature of the medium, then we have

$$T'(t) = -k(T(t) - T_o)$$

Applying Rohit Transform (RT), we have

$$r\,G(r) - r^3T(0) = -k(G(r) - r^2T_o)$$

At t = 0, $T(0) = T_1$, therefore, solving and rearranging the equation, we have

$$G(r) = \frac{T_1\,r^3}{r+k} + k\,T_o\frac{r^2}{r+k}$$

Or

$$G(r) = \frac{T_1 r^3}{r+k} + T_o[\,r^2 - \frac{r^3}{r+k}]$$

Taking inverse Rohit Transform (RT), we have

$$T(t) = T_1e^{-kt} + T_o[1 - e^{-kt}\,]$$

APPLICATION 6:

Under certain conditions, cane sugar is converted into dextrose at a rate proportional to the amount unconverted [1]. We will apply Rohit Transform (RT) to find the amount of cane sugar converted at any instant t.

Solution:

Let 'M' be the amount of cane sugar initially and 'm' be the amount of cane sugar converted at any instant t, then we have

$$m'(t) = k(M - m(t))$$

Or

$$m'(t) = -k(m(t) - M)$$

Applying Rohit Transform (RT), we have

$$r\,G(r) - r^3m(0) = -k(G(r) - r^2M)$$

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

$$G(r) = kM\,\frac{r^2}{r+k}$$

Or

$$G(r) = M[\,r^2 - \frac{r^3}{r+k}]$$

Taking inverse Rohit Transform (RT), we have

$$m(t) = M\,[1 - e^{-kt}\,]$$

APPLICATION 7:

RL series circuit with sinusoidal voltage:

Let $I(t)$ be the current flowing in the RL series circuit with sinusoidal voltage $E\sin wt$, at any time t, then by voltage law [2], [19], we have

$$L\,I'(t) + RI(t) = E\sin wt$$

Or

$$I'(t) + \frac{R}{L}I(t) = \frac{E}{L}\sin wt,$$

We will apply Rohit Transform (RT) to obtain the current in the circuit at instant t and also find the current when t increases indefinitely.

Solution:

$$I'(t) + \frac{R}{L}I(t) = \frac{E}{L}\sin wt$$

Applying Rohit Transform (RT), we have

$$rG(r) - r^3I(0) + \frac{R}{L}G(r) = \frac{E}{L}\frac{w\,r^3}{r^2+w^2}$$

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

$$G(r) = \frac{E}{L}\frac{w\,r^3}{(r^2+w^2)(r+\frac{R}{L})}$$

Or

$$G(r) = \frac{Ew}{L}\frac{r^3}{2iw(\frac{R}{L}+iw)(r-iw)} - \frac{Ew}{L}\frac{r^3}{2iw\left(\frac{R}{L}-iw\right)(r+iw)} + \frac{Ew}{L}\frac{r^3}{\left(\frac{R}{L}+r\right)\{\left(\frac{R}{L}\right)^2+w^2\}}$$

Taking inverse Rohit Transform (RT) and solving, we have

$$I(t) = \frac{E}{L}\frac{e^{iwt}}{2i(\frac{R}{L}+iw)} - \frac{E}{L}\frac{e^{-iwt}}{2i\left(\frac{R}{L}-iw\right)} + \frac{Ew}{L}\frac{e^{-\frac{R}{L}t}}{\{\left(\frac{R}{L}\right)^2+w^2\}}$$

When t increases indefinitely, $e^{-\frac{R}{L}t}$ tends to zero, so

$$I(t) = \frac{E}{L}\frac{e^{iwt}}{2i(\frac{R}{L}+iw)} - \frac{E}{L}\frac{e^{-iwt}}{2i\left(\frac{R}{L}-iw\right)}$$

Or

$$I(t) = \frac{E}{2iL}\left[\frac{e^{iwt}}{\left(\frac{R}{L}+iw\right)} - \frac{e^{-iwt}}{\left(\frac{R}{L}-iw\right)}\right]$$

APPLICATION 8:

The rate at which ice melts is proportional to the amount of ice at that instant [1], [10]. We will apply the Rohit Transform (RT) to find the amount of ice at any instant t.

Solution:

Let 'M' be the amount of ice initially at t = 0 and 'm' be the amount of ice at any instant t, then

$$m'(t) = -km$$

Applying Rohit Transform (RT), we have

$$r\,G(r) - r^3m(0) = -kG(r)$$

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

$$G(r) = \frac{M\,r^3}{r+k}$$

Taking inverse Rohit Transform (RT), we have

$$m(t) = Me^{-kt}$$

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VI. CONCLUSION

The operational properties of a novel integral transform named Rohit Transform (RT) and its applications for analyzing the boundary value problems in Science and Engineering have been demonstrated. Like other transforms, the Rohit Transform (RT) has also been found to be a very effective integral transform for analyzing the boundary value problems described by linear ordinary differential equations with constant coefficients in Science and Engineering.

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