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Propounding a new Integral Transform: Gupta Transform with Applications in Science and Engineering

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Abstract: In this paper, a novel integral transform named as Gupta Transform is proposed. The functional characteristics of Gupta Transform are discussed. The Gupta Transform of elementary functions, and some of the derivatives of a function are obtained. The initial value problems in Science and Engineering are analyzed by the application of Gupta Transform. It is revealed that the initial value problems in Science and Engineering are easily analyzed by applying Gupta Transform.

Index Terms: Gupta Transform, Initial value Problem

I. INTRODUCTION

There are 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], etc. which are widely used for analyzing the initial value problems in Science and Engineering [10], [11], [12], [13], [14], [15], [16]. In this paper, Rahul Gupta and Rohit Gupta together proposed a novel integral transform named as 'Gupta Transform' and applied it for analyzing some initial value problems in Science and Engineering.

II. DEFINITION OF GUPTA TRANSFORM

Let g(y) is continuous function on any interval for $y \geq 0$. The Gupta Transform of g(y) is defined as $\dot{R}\{g(y)\} = \frac{1}{q^3}\int_0^\infty e^{-qy}\, g(y)dy = G(q)$, provided that the integral is convergent, where q may be a real or complex parameter and Ṙ is the Gupta Transform operator.

Gupta Transform of Elementary Functions

According to the definition of Gupta Transform,

$\dot{R}\{g(y)\} = \frac{1}{q^3}\int_0^\infty e^{-qy}\, g(y)dy$, then

1. $$\dot{R}\{1\} = \frac{1}{q^3}\int_0^\infty e^{-qy}\; dy$$

$$= -\frac{1}{q^4}(\,e^{-\infty} - \,e^{-0})$$

$$= -\frac{1}{q^4}(0-1)$$

$$= \frac{1}{q^4}$$

Hence $\dot{R}\{1\} = \frac{1}{q^4}$

2. $$\dot{R}\,\{y^n\} = \frac{1}{q^3}\int_0^\infty e^{-qy}\, y^n\, dy$$

$$= \frac{1}{q^3}\int_0^\infty e^{-z}\left(\frac{z}{q}\right)^n \frac{dz}{q} \quad ,z = qy$$

$$= \frac{1}{q^{n+4}}\int_0^\infty e^{-z}\,(z)^n dz$$

Applying the definition [1] of gamma function,

$$\dot{R}\,\{y^n\} = \frac{1}{q^{n+4}}\Gamma(n+1)$$

$$= \frac{1}{q^{n+4}}n!$$

$$= \frac{n!}{q^{n+4}}$$

Hence $\dot{R}\{y^n\} = \frac{n!}{q^{n+4}}$

3. $$\dot{R}\,\{\,sinby\} = \frac{1}{q^3}\int_0^\infty e^{-ry}\, sinby\; dy$$

$$= \frac{1}{q^3}\int_0^\infty e^{-qy}\left(\frac{e^{iby} - e^{-iby}}{2i}\right)dy$$

$$= \frac{1}{q^3}\int_0^\infty \left(\frac{e^{-(q-ib)y} - e^{-(q+ib)y}}{2i}\right) dy$$

$= -\frac{1}{q^3}\frac{1}{2i(q-ib)}\ (e^{-\infty} - e^{-0}) \quad + \frac{1}{q^3}\frac{1}{2i(q+ib)}\ (e^{-\infty} - e^{-0})$

$= \frac{1}{q^3}\frac{1}{2i(q-ib)} - \frac{1}{q^3}\frac{1}{2i(q+ib)}$

$= \frac{1}{q^3}\frac{b}{q^2+b^2}$

Hence $R\{sinby\} = \frac{b}{q^3(r^2+b^2)}$

4. $R\{sinhby\} = \frac{1}{q^3}\int_0^\infty e^{-qy}\, sinhby\, dy$

$$= \frac{1}{q^3}\int_0^\infty e^{-qy}\left(\frac{e^{by} - e^{-by}}{2}\right) dy$$

$$= \frac{1}{q^3}\int_0^\infty \left(\frac{e^{-(q-b)y} - e^{-(q+b)y}}{2}\right) dy$$

$= -\frac{1}{q^3}\frac{1}{2(q-b)}\ (e^{-\infty} - e^{-0})$

$+\frac{1}{q^3}\frac{1}{2(q+b)}\ (e^{-\infty} - e^{-0})$

$= \frac{1}{q^3}\frac{1}{2(q-b)} - \frac{1}{q^3}\frac{1}{2(q+b)}$

$= \frac{1}{q^2}\frac{b}{q^2-b^2}$

Hence $R\{sinhby\} = \frac{b}{q^2(q^2-b^2)}$

5. $R\{cosby\} = \frac{1}{q^3}\int_0^\infty e^{-qy}\, cosby\, dy$

$$= \frac{1}{q^3}\int_0^\infty e^{-qy}\left(\frac{e^{iby} + e^{-iby}}{2}\right) dy$$

$$= \frac{1}{q^3}\int_0^\infty \left(\frac{e^{-(q-ib)y} + e^{-(q+ib)y}}{2}\right) dy$$

$= -\frac{1}{q^3}\frac{1}{2(r-ib)}\ (e^{-\infty} - e^{-0}) \quad -\frac{1}{q^3}\frac{1}{2(r+ib)}\ (e^{-\infty} - e^{-0})$

$= \frac{1}{q^3}\frac{1}{2(r-ib)} + \frac{1}{q^3}\frac{1}{2(r+ib)}$

$= \frac{1}{q^2(r^2+b^2)}$

Hence $R\{cosby\} = \frac{1}{q^2(r^2+b^2)}$

6. $R\{coshby\} = \frac{1}{q^3}\int_0^\infty e^{-qy}\, coshby\, dy$

$$= \frac{1}{q^3}\int_0^\infty e^{-qy}\left(\frac{e^{by} + e^{-by}}{2}\right) dy$$

$$= \frac{1}{q^3}\int_0^\infty \left(\frac{e^{-(q-b)y} + e^{-(q+b)y}}{2}\right) dy$$

$= -\frac{1}{q^3}\frac{1}{2(q-b)}\ (e^{-\infty} - e^{-0})$

$-\frac{1}{q^3}\frac{1}{2(q+b)}\ (e^{-\infty} - e^{-0})$

$= \frac{1}{q^3}\frac{1}{2(q-b)} + \frac{1}{q^3}\frac{1}{2(q+b)}$

$= \frac{1}{q^2(q^2-b^2)}$

Hence $\dot{R}\{coshby\} = \frac{1}{q^2(q^2-b^2)}$

7. $\dot{R}\{e^{by}\} = \frac{1}{q^3}\int_0^\infty e^{-qy}\, e^{by}\, dy$

$$= \frac{1}{q^3}\int_0^\infty \left(e^{-(q-b)y}\right) dy$$

$= -\frac{1}{q^3}\frac{1}{(q-b)}\ (e^{-\infty} - e^{-0})$

$= \frac{1}{q^3}\frac{1}{(q-b)}$

Hence $\dot{R}\{e^{by}\} = \frac{1}{q^3(q-b)}$

8. $\dot{R}\{\delta(y-b)\} = \frac{1}{q^3}\int_0^\infty e^{-qy}\, \delta(y-b)\, dy$

Since the unit step function $\delta(y-b), b \geq 0$, is defined [1-2] 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

$$\dot{R}\{\delta(y-b)\} = \frac{1}{q^3}\int_b^\infty e^{-qy}\ dy$$

$= -\frac{1}{q^4}\ (e^{-\infty} - e^{-bq})$

$= \frac{1}{q^4}\ e^{-bq}$

Hence $\dot{R}\{\delta(y-b)\} = \frac{1}{q^4}\ e^{-bq}$

Hence we found that the Gupta Transform of some elementary functions are

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

Inverse Gupta Transform of Elementary Functions

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

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

The Inverse Gupta Transform of some elementary functions are given below

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

Gupta Transform of derivatives

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

$$\dot{R}\{g'(y)\} = \frac{1}{q^3}\int_0^\infty e^{-qy}\, g'(y)dy$$

Integrating by parts and applying limits, we get
$\dot{R}\{g'(y)\}$

$=\frac{1}{q^3}\{-g(0) - \int_0^\infty -qe^{-qy}\, g(y)dy\} = \frac{1}{q^3}\{-g(0) + q\int_0^\infty e^{-qy}\, g(y)dy\}$

$= \mathrm{q}G(q) - \frac{1}{q^3} g(0)$

Hence

$$\dot{R}\{g'(y)\} = qG(q) - \frac{1}{q^3} g(0)$$

Since

$\dot{R}\{g'(y)\} = q\dot{R}\{g(y)\} - \frac{1}{q^3} g(0)$, Therefore, on replacing g(y) by $g'(y)$ and $g'(y)$ by $g''(y)$, we have

$$\dot{R}\{g''(y)\} = q\dot{R}\{g'(y)\} - \frac{1}{q^3} g'(0)$$

$$= \mathrm{q}\left\{\mathrm{q}\dot{R}\{g(y)\} - \frac{1}{q^3} g(0)\right\} - \frac{1}{q^3} g'(0)$$

$$= q^2\dot{R}\{g(y)\} - \frac{1}{q^2} g(0) - \frac{1}{q^3} g'(0)$$

$$= q^2 G(q) - \frac{1}{q^2} g(0) - \frac{1}{q^3} g'(0)$$

Hence

$$\dot{R}\{g''(y)\} = q^2 G(q) - \frac{1}{q^2} g(0) - \frac{1}{q^3} g'(0)$$

And so on.

III. APPLICATIONS OF GUPTA ANSFORM TO PHYSICS PROBLEMS

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 $v'(\mathrm{t}) = g - kv,$ where v is the velocity when the particle has fallen a distance y in time t from rest and kv is the air resistance. We will Apply Gupta Transform to solve the equation of motion of the particle.

Solution:

The equation of motion of the particle is given by

$$v'(\mathrm{t}) = g - kv(t)$$

Applying Gupta Transform, we have

$$\mathrm{q}\, G(q) - \frac{1}{q^3} v(0) = g\frac{1}{q^4} - kG(q)$$

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

$$G(r) = \frac{g}{q^4(q+k)}$$

Or

$$G(r) = \frac{g}{k}[\frac{1}{q^4} - \frac{1}{q^3(q+k)}]$$

Taking inverse Gupta Transform, 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, we have [17]

$$L\, I'(\mathrm{t}) + RI(t) = E$$

Or

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

We will apply Gupta Transform to obtain the current in the circuit at instant t.

Solution:

Applying Gupta Transform, we have

$$qG(q) - \frac{1}{q^3} I(0) + \frac{R}{L} G(q) = \frac{E}{L}\frac{1}{q^4}$$

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

$$G(q) = \frac{E}{L}\frac{1}{q^4(q+\frac{R}{L})}$$

Or

$$G(q) = \frac{E}{R}[\frac{1}{q^4} - \frac{1}{q^3(q+\frac{R}{L})}]$$

Taking inverse Gupta Transform, 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 mean position at any instant t, the differential equation describing the motion of the particle is given by

$$x''(\text{t}) + w^2x = 0, w^2 = k/m.$$

We will apply Gupta Transform to find the displacement of the particle at any instant t.

Assume that at t = 0, x(0) = 0 and $x'(0) = 1$.

Solution:

$$x''(\text{t}) + w^2x = 0$$

Applying Gupta Transform, we have

$$q^2G(r) - \frac{1}{q^2}x(0) - \frac{1}{q^3}x'(0) + w^2G(q) = 0$$

At t = 0, x(0) = 0 and $x'(0) = 1$, solving and rearranging the equation, we have

$$G(q) = \frac{1}{q^3(q^2+w^2)}$$

Taking inverse Gupta Transform 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. We will apply Gupta Transform 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

$$n'(\text{t}) = -\lambda n$$

Applying Gupta Transform, we have

$$q\,G(q) - \frac{1}{q^3}n(0) = -\lambda G(q)$$

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

$$G(q) = \frac{1}{q^3}\frac{N}{q+\lambda}$$

Taking inverse Gupta Transform, we have

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

APPLICATION 5:

The rate of decrease of temperature of the body is proportional to the difference between the temperature of the body and that of the medium. We will apply Gupta Transform 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 tand T_o be the temperature of the medium, then we have

$$T'(\text{t}) = -k(T(t) - T_o)$$

Applying Gupta Transform, we have

$$q\,G(q) - \frac{1}{q^3}T(0) = -k(G(q) - \frac{1}{q^4}T_o)$$

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

$$G(q) = \frac{1}{q^3}\frac{T_1}{q+k} + k\,T_o\frac{1}{q^4}\frac{1}{r+k}$$

Or

$$G(q) = \frac{1}{q^3}\frac{T_1}{q+k} + T_o[\frac{1}{q^4} - \frac{1}{q^3}\frac{1}{q+k}]$$

Taking inverse Gupta Transform, we have

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

APPLICATION 6:

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, we have [18]

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

Or

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

We will apply Gupta Transform to obtain the current in the circuit at instant t.

Solution:

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

Applying Gupta Transform, we have

$$qG(q) - \frac{1}{q^3}I(0) + \frac{R}{L}G(q) = \frac{E}{L}\frac{1}{q^3}\frac{w}{q^2+w^2}$$

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

$$G(q) = \frac{E}{L}\frac{1}{q^3}\frac{w}{(q^2+w^2)(q+\frac{R}{L})}$$

Or $G(q) =$

$$\frac{Ew}{L}\frac{1}{q^3}\frac{1}{2iw(\frac{R}{L}+iw)(r-iw)} - \frac{Ew}{L}\frac{1}{q^3}\frac{1}{2iw\left(\frac{R}{L}-iw\right)(r+iw)} + \frac{Ew}{L}\frac{1}{q^3}\frac{1}{\left(\frac{R}{L}+r\right)\{\left(\frac{R}{L}\right)^2+w^2\}}$$

Taking inverse Gupta Transform and solving, we have

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

APPLICATION 7:

The rate at which ice melts is proportional to the amount of ice at that instant. We will apply Gupta Transform 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

$$m'(\mathrm{t}) = -km$$

Applying Gupta Transform, we have

$$q\,G(q) - \frac{1}{q^3}m(0) = -kG(q)$$

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

$$G(q) = \frac{1}{q^3}\frac{M}{q+k}$$

Taking inverse Gupta Transform, we have

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

APPLICATION 8:

Parallel RC network connect a steady current source:

We will solve the differential equation [18], [20]:

$C\,V'(\mathrm{t}) + V(t)/R = I,$

Or

$V'(\mathrm{t}) + \frac{1}{RC}V(t) = \frac{I}{C},$ for analyzing the Parallel RC network connect a steady current source byGupta Transform.

Solution:

Applying Gupta Transform, we have

$$qG(q) - \frac{1}{q^3}V(0) + \frac{1}{RC}G(q) = \frac{I}{C}\frac{1}{q^4}$$

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

$$G(q) = \frac{I}{C}\frac{1}{q^4(q+\frac{1}{RC})}$$

Or

$G(q) = \frac{I}{R}[\frac{1}{q^4} - \frac{1}{q^3(q+\frac{1}{RC})}]$

Taking inverse Gupta Transform, we have

$V(t) = \frac{I}{R}[1 - e^{-\frac{1}{RC}t}]$

IV. CONCLUSION

The functional characteristics of the novel integral transform named as "Gupta Transform" and its applications for analyzing the initial value problems in Science and Engineering have been demonstrated. Like other transforms, the Gupta Transform has also been found to be very effective integral transform for analyzing the initial value problems in Science and Engineering.

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