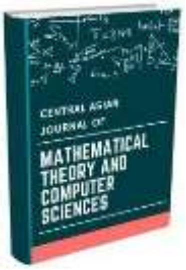

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Article

Review on Triple Integral Transforms and Their Inverses

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Abstract: Transformations involving triple-integrals are the basis for the solutions of a number of three-dimensional partial differential equations that arise in physics, engineering, and applied sciences. Although many triple transforms are available (e.g., Laplace, Fourier, Aboodh, Shehu, Ezaki, and various hybrid triple transforms), to the best of our knowledge, a detailed systematic comparative review is not yet available that compares different triple transforms with respect to their definitions and kernels, inverse formulations, and applications. This paper fills this gap by giving an overview of most important, widespread triple integral transforms, whereby introducing their formal definitions, inverse transforms as well as structural properties. Analytical behaviors of benign configurations are presented in solving different problems such as heat, wave, diffusion, and boundary value problems, which differ due to differences in kernel structures, convergence conditions, and their parameter configuration. We show that all the triple transforms impose preservation of linearity and algebraic simplification of differential operators, but each possess respective benefits specific to final transformed domain characteristics and boundary conditions. The results highlight the significance of careful selection of an adequate transform based on the structural characteristic of the problem under investigation and that future research should include generalized and hybrid triple transforms coupled with numerical methods to provide a more time-efficient analytical–numerical model.

Keywords: Integral transforms , Triple integral transforms, Inverse of Triple Integral Transform

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1. Introduction

Triple integral transforms are an important mathematical tool used to efficiently find exact solutions to difficult partial differential equations, such as those related to heat, waves, Laplace's equations, and general telegraph equations in physics and engineering. They simplify difficult three-dimensional, multivariable problems by transforming derivatives into simple algebraic equations.

Many researchers have presented and proposed numerous triple integral transforms, and each of these integral transforms has importance in a specific application in physics, medicine, or engineering. These applications are nothing but partial differential equations [1][2][3][4][5][6][7][8][9][10][11][12].

This paper provides a review of the most important and well-known triple integral transforms in the applications of partial differential equations, as mentioned in the second item. This paper is of great benefit to researchers in understanding these transforms [2]

Triple integral transforms represent an advanced analytical tool for solving three-dimensional mathematical models. Their importance extends beyond theoretical mathematics into practical applications in heat transfer, fluid mechanics, electromagnetic wave propagation, and diffusion models in three-dimensional media.

When dealing with partial differential equations involving three independent variables, direct analytical solutions are often highly complex. Triple integral transforms simplify these systems by converting differential operators into algebraic expressions in the transform domain. This significantly reduces computational difficulty and enables the derivation of exact or semi-exact solutions that can later be recovered through inverse transforms. [3]

Differences in the transform kernel distinguish one transform from another. Each kernel provides specific analytical advantages depending on the nature of the governing equation and the imposed boundary or initial conditions. Some transforms are more efficient for problems with initial conditions, while others are better suited for unbounded domains or oscillatory behavior.

The increasing use of three-dimensional numerical modeling in engineering and applied sciences has led to renewed interest in triple transforms, particularly in developing analytical tools that complement numerical simulations. [4]

2. Methodology

Background This work uses a systematic analytical review approach to analyze the former triple integral transforms and inversions as outlined in the attached manuscript. The first stage of the methodology identifies which of the main triple integral transforms that have been studied in the literature so far, which includes, among other ones, triple Laplace, triple Fourier, triple Aboodh, triple Shehu, triple Ezaki, triple g-transformation, and some hybrid transform, such as Laplace–Aboodh–Sumudu and Laplace–Sumudu transforms [7,8,9,10,11,12,13,14,15,16,17,18,19,20]. We discuss each transform by its formal mathematical definition, kernel structure, domain of integration and convergence conditions. Inverse formulations are also investigated to understand how the original function can be reconstructed from its transform. This paper develops a framework for a comparative analysis of similarities and differences among the transforms, with a focus on linearity, differentiation properties, dependence on parameters, and applicability to 3D PDEs. In addition, the study explores the way in which each transform maps differential operators to algebraic operations and reviews the appropriateness of each approach to solving heat, wave, diffusion and boundary value problems. The emphasis is on recognizing the structural properties that set each transform apart in turn, particularly differences in kernels and parameters set-ups. The approach is based on theoretical calculations and interpretation of mathematical expressions in the literature instead of numerical experiments. By this systematic comparative analysis, this research specifies the efficiency of analysis and feasibleness of application for each triple transform in the context

$$F(p,q,r) = L_3\{f(x,y,z)\} = L[L\{L(f(x,y,z); x \to p); y \to q\}; z \to r]$$

$$\therefore F(p,q,r)=L_3[f(x,y,z)]=\int_0^\infty\int_0^\infty\int_0^\infty f(x,y,z)\,e^{-(px+qy+rz)}\,dxdydz$$

Provided the integral exists .

The definitions presented in this section reflect the mathematical evolution from single and double integral transforms to triple integral forms. Conceptually, a triple transform extends classical transforms such as Laplace or Fourier into a three-variable framework.

This extension requires stronger convergence conditions and careful treatment of linearity, shifting properties, differentiation rules, and convolution structures. Despite these technical requirements, triple transforms preserve the essential structural properties of classical transforms while expanding their applicability to higher-dimensional systems. [6]

Each transform introduced here is characterized by a specific kernel and integration domain, which determine its analytical behavior and range of applications.

Definition (2.2), [7]

The Fourier transform of the function f(t) is in the infinite interval (-∞,+∞) ,if f(t) satisfies the Dirichlet Hurley Condition on any finite interval; and the integral ∫_(-∞)^(+∞)▒■(∣ &F(t)& ∣ dt) converges , it can be expressed as a Fourier integral Considering function f(x,y,z) , we use Fourier's triple integral transform method and obtain

$$f(x,y,z) = \iiint_{-\infty}^{+\infty} \bar{f}\ \left(w_1, w_2, w_3\right) e^{j(w_1 x + w_2 y + w_3 z)} dw_1 dw_2 dw_3 \quad \text{and}$$

f ̅(w_1, 〖w_2〗_,w_3)=1/(2π)^3 ∭_(-∞)^(+∞)▒f(x,y,z) e^(-j(w_1 x+w_2 y+w_3 z)) dxdydz

Then we define two separate position vectors r=xi+yi+zk and w=w_1 i+w_2 j+w_3 k So.

$$f(r) \iiint_{-\infty}^{+\infty} \bar{f}\ (w) e^{j(w.r)} dw_1 dw_2 dw_3 \quad \text{and}$$

f ̅(w)=1/(2π)^3 ∭_(-∞)^(+∞)▒f (w) e^(-j(w.r)) dxdydz .

The triple Laplace transform is one of the most widely used tools in engineering mathematics, particularly in three-dimensional heat conduction and diffusion problems. Its structure allows the systematic reduction of partial differential equations into algebraic forms.

In applied contexts, this transform is especially effective for problems involving zero initial conditions, as derivatives in the original domain become algebraic expressions in the transform domain. Its linearity also facilitates the analysis of composite systems containing multiple source terms.

The inverse transform plays a central role in reconstructing the solution in the original domain, often relying on contour integration techniques or established transform tables.

Definition (2.3), [8]

Let f be continuous function of three variables, then the triple Aboodh transform off(x,y,t) is defined by .

$$k(p,q,r) = A_x A_y A_t\{f(x,y,t)\} = \frac{1}{pqr} = \iiint_0^{\infty} e^{-(px+qy+st)} f(x,y,t)\,dxdydt$$

Ln addition, the inverse of triple Aboodh transform is given by(.)

$$f(x,y,t)\; A_x^{-1}A_y^{-1}A_t^{-1} =$$
$$\frac{1}{2\pi i}\int_{\alpha-i\infty}^{\alpha+i\infty} p\, e^{px}\left[\frac{1}{2\pi i}\int_{\beta-i\infty}^{\beta+i\infty} q\, e^{qy}\left[\frac{1}{2\pi i}\int_{\gamma-i\infty}^{\gamma+i\infty} r\, e^{rt}\, k(p,q,r)dr\right]dq\right]dp$$

Definition (2.4), [9]

The Triple Shehu transform of the function f(x,y,t) is given by ;

$$H_{x,y,t}^{-3}\,\{f(x,y,t)\} = F[(a\,,b\,,c),(h\,,k,l)]$$
$$= \int_0^{\infty}\int_0^{\infty}\int_0^{\infty} e^{-\left[\frac{ax}{h}+\frac{by}{k}+\frac{ct}{l}\right]}\; f(x,y,t)\,dx\,dy\,dt$$

Where x,y,t≥0 and a ,b,c,h,k and l are parameters .

The triple Fourier transform is primarily applied to problems defined over infinite or unbounded domains. It is particularly effective for oscillatory functions and wave phenomena.

Its spectral nature allows the decomposition of a function into frequency components, making it fundamental in signal processing, quantum mechanics, and wave propagation analysis.

The requirement that the function satisfies Dirichlet conditions ensures convergence, which restricts its use to specific classes of functions but guarantees precise spectral representation

Definition (2.5), [10]

Let f(x,y,t) be a function that can be expressed as convergent infinite series , and let (x,y,t)∈R_3^+, then, the triple Ezaki transform is denoted by:

$$E_3[f(x,y,t)\,\colon\,(p,s,\delta)] = ps\delta\int_0^{\infty}\int_0^{\infty}\int_0^{\infty} e^{-\frac{x}{p}-\frac{y}{s}-\frac{t}{\delta}} f(x,y,t)dxdydt,$$

Where x,y,t>0 andp,s,δ are transform parameters for x,y and t respectively, whenever the improper integral is convergent.

The triple Aboodh transform is a relatively recent development designed to overcome certain limitations of the classical Laplace transform.

It simplifies the handling of some differential equations with constant coefficients and can provide more compact solution forms in certain diffusion and wave models.

Its inverse formulation is structured in a way that enables systematic recovery of the original function without excessive computational complexity

Definition (2.6), [11]

The triple g- transformation and denote it as T_{3sg} . This transformation consider as generalized to some types of triple transformation. We defined it as the following form :

$$T_{3sg}\{f(x,y,z)\} = p(s)\int_0^{\infty}\int_0^{\infty}\int_0^{\infty} e^{q_1(s)x-q_2(s)y-q_3(s)z} f(x,y,z)dxdydz.$$

The triple Shehu transform introduces a modified kernel that increases flexibility in analytical modeling.

Its parameter structure allows adaptation to various classes of differential equations. This adaptability makes it suitable for models involving parametric systems or coupled processes.

Because of its generalized structure, it can sometimes reduce to other known transforms under specific parameter choices

Definition (2.7), [12]

Let f be a continuous function of three variables say $x, y, t > 0$; then ,the triple Laplace- Aboodh- Sumudu transform of $f(x,y,t)$ is denoted by the operator $L_x, A_y, S_t\{f(x,y,t)\} = F(p,q,r)$ and defined by.

$$L_x A_y S_t\{f(x,y,t)\} = F(p,q,r) = \frac{1}{qr}\int_0^\infty \int_0^\infty \int_0^\infty e^{-\left(px+qy+\frac{t}{r}\right)} f(x,y,t)dxdydt$$

Provide the integral exists.

The inverse triple Laplace- Aboodh- Sumudu transform is defined by

$$f(p,q,r) = L_x^{-1}A_y^{-1}S_t^{-1}[f(x,y,t)]$$
$$= \frac{1}{(2\pi i)^3}\int_{R_1-i\infty}^{R_1+i\infty} p\, e^{px}\left\{\int_{R_2-i\infty}^{R_2+i\infty} q\, e^{qy}\left\{\int_{R_3-i\infty}^{R_3+i\infty} \frac{1}{r}\, e^{\frac{t}{r}}\ \ F(p,q,r)dr\right\}dq\right\}dp$$

Where $k_1 k_2 and\ k_3$ are real constants.

The triple Ezaki transform is particularly useful when the function under consideration can be expressed as a convergent infinite series.

This property makes it effective in solving problems that naturally admit series-based solutions.

In engineering applications, it supports analytical modeling where approximation through power series expansions is common

Definition (2.8), [13]

This section is concerned with the presentation of the new general triple integral transform in three-dimensional

$$\mathbb{T}_3\{g(x,y,t),(r,s,v)\} = \mathbb{G}_T(r,s,v)$$
$$= \mathbb{T}_x\left\{\mathbb{T}_y\{\mathbb{T}_t\{g(x,y,t), t \to v\}y \to s\}x \to r\right\}, r,s,v > 0$$
$$= p(r)\int_0^\infty e^{-w(r)x}\left(q(s)\int_0^\infty e^{-\psi(s)y}\left(u(v)\int_0^\infty e^{-\varphi(v)t}\, g(x,y,t)dt\right)dy\right)dx$$
$$= p(r)q(s)u(v)\int_0^\infty \int_0^\infty \int_0^\infty e^{-w(r)x-\psi(s)y-\varphi(v)t} g(x,y,t)dxdydt.$$

Provided that all integrals exists for some $w(r), \psi(s)$ and $\varphi(v)$, where $w(r), \psi(s)$ and $\varphi(v)$

Are the transform functions for $x, y,$ and t , respectively.

The inverse GTT is defined by the following equation:

$$\mathbb{T}_3^{-1}\{\mathbb{G}_T\,(r,s,v)\} = \mathbb{T}_x^{-1}\left\{\mathbb{T}_y^{-1}\{\mathbb{T}_t^{-1}\{\mathbb{G}_T(r,s,v)\}\}\right\} = g(x,y,t)$$

$$= \frac{1}{2\pi i}\int_{a-i\infty}^{a+i\infty} \frac{1}{p(r)} e^{w(r)x}\, dr\, \frac{1}{2\pi i}\int_{b-i\infty}^{b+i\infty} \frac{1}{q(s)} e^{\psi(s)y}\, ds\, \frac{1}{2\pi i}\int_{a-i\infty}^{ai+\infty} \frac{1}{u(v)} e^{\varphi(v)t}\ \mathbb{G}_T(r,s,v)dv$$

$$= \mathbb{S}_3[g(x,y,t)] = \frac{1}{rsv}\int_0^\infty\int_0^\infty\int_0^\infty e^{(1)-(1)-(1)}[g(x,y,t)]dxdydt.$$

Where a, b and c are the real constants.

The triple g-transformation serves as a generalized framework that encompasses several special cases of triple transforms.

Its theoretical significance lies in its ability to unify different transform structures within a single formulation.

By selecting appropriate transformation functions, specific transforms can be derived, making it a powerful analytical tool

Definition (2.9), [14]

The triple Laplace- Sumudu transform is a linear integral transform of the function $u(x,y,t)$ three variables $x > 0$, $y > 0$ and $t > 0$ is defined by

$$L_x L_y S_z\{u(x,y,t)\} = \frac{1}{\sigma}\int_0^\infty\int_0^\infty\int_0^\infty e^{-p_1x-p_2y\frac{1}{\sigma}}u(x,y,t)dxdydt\,.$$

The triple Laplace-Sumudu transform is denoted by $\bar{u}(p_1, p_2\,, \sigma\,) = L_x L_y S_z\{u(x,y,t)\}$

Clearly, the triple Laplace- Sumudu transform is linear integral transformation as Show below .For any scalars α , β and the functions $u(x,y,t)$, $v(x,y,t)$ of three variables, we have

$$L_x L_y S_t\{\alpha u(x,y,t) + \beta v(x,y,t)\}$$

$$= \frac{1}{\sigma}\int_0^\infty\int_0^\infty\int_0^\infty e^{-p_1x-p_2y\frac{1}{\sigma}}[\alpha u(x,y,t) + \beta v(x,y,t)]dxdydt$$
$$+\frac{1}{\sigma}\int_0^\infty\int_0^\infty\int_0^\infty e^{-p_1x-p_2y\frac{1}{\sigma}}\alpha u(x,y,t)dxdydt$$
$$+\frac{1}{\sigma}\int_0^\infty\int_0^\infty\int_0^\infty e^{-p_1x-p_2y\frac{1}{\sigma}}\beta v(x,y,t)dxdydt\,.$$

$$= \frac{\alpha}{\sigma}\int_0^\infty\int_0^\infty\int_0^\infty e^{-p_1x-p_2y\frac{1}{\sigma}}u(x,y,t)dxdydt\,.$$

$$+\frac{\beta}{\sigma}\int_0^\infty\int_0^\infty\int_0^\infty e^{-p_1x-p_2y\frac{1}{\sigma}}v(x,y,t)dxdydt\,.$$

$$= \alpha L_x L_y S_t\left\{u(x,y,t) + = \beta L_x\, L_y\, S_t\{v(x,y,t)\}\right\}.$$

Definition (2.10), [15]

The triple complex integral transform of a function $G(y,z,h)$, involving three variables y, z ,

And h , defined within the first octant of the yzh -plans , is expressed as a triple integral in the following form :

$$g(b,m,n) = (S_a^c)_3[G(y,z,h)]$$

$$= S_a^c\{S_a^c(S_a^c[G(y,z,h); y \to b]; z \to m); h \to n\}$$

Therefore

$$g(b,m,n) = (S_a^c)_3[G(y,z,h)]$$

$$= \frac{1}{f^{\alpha}} \int_0^{\infty} \int_0^{\infty} \int_0^{\infty} G(y,z,h) e^{-jf^{\delta}(by+mz+nh)} dydzdh$$

Where j is a complex number , f, b, m, n are complex parameters , $Im\left(f^{\delta} b\right) < 0$, $Im\left(f^{\delta} n\right) < 0, f^{\alpha} \neq 0$ and α, δ are real numbers. $g(b) = S_a^c[G(y); y \to b]$ $of g(y)$ and to be define by

$$g(b) = S_a^c[G(y)] = \frac{1}{f^{\alpha}} \int_0^{\infty} G(y) e^{-jf^{\delta}(by)} dy \quad Re(y) > 0$$

The inverse complex integral transform of $g(y)$ is represented and defined as follows : [16]

$$G(y) = \{S_a^c\}^{-1}[g(b)] = \frac{1}{2\pi f^{\alpha}} \int_{r-\infty}^{r+\infty} g(b) e^{-jf^{\delta}(by)} db \quad r \geq 0 .$$

Mixed transforms such as the Triple Laplace-Aboodh-Sumudu transform combine features of multiple classical transforms.

This hybrid structure enhances flexibility and allows the treatment of more complex systems that cannot be simplified by a single transform alone.

Such transforms are especially useful in multidimensional models with mixed boundary conditions. [17]

Definition (2.11), [18]

Let $\Phi\left(\frac{p^{\mu}}{\mu}, \frac{q^{\eta}}{\eta}, \frac{r^{\delta}}{\delta}\right)$ be a piecewise functions continuous function of exponential order. The conformable triple Laplace- Sumudu transform $(CTLST)$,denoted by $L_p^{\mu} L_q^{\eta} L_r^{\delta}$, is defined as

$$L_p^{\mu} L_q^{\eta} L_r^{\delta} = \left[\Phi\left(\frac{p^{\mu}}{\mu}, \frac{q^{\eta}}{\eta}, \frac{r^{\delta}}{\delta}\right)\right] = \frac{1}{\varphi} \int_0^{\infty} \int_0^{\infty} \int_0^{\infty} e^{-\theta_1\left(\frac{p^{\mu}}{\mu}\right) - \theta_2\left(\frac{q^{\eta}}{\eta}\right) - \theta_3\left(\frac{r^{\delta}}{\delta}\right)}$$

$$\times \Phi\left(\frac{p^{\mu}}{\mu}, \frac{q^{\eta}}{\eta}, \frac{r^{\delta}}{\delta}\right) dpdqdr$$

$$= \Phi(\theta_1, \theta_2, \theta_3)$$

Where $\frac{p^{\mu}}{\mu} > 0, \frac{q^{\eta}}{\eta} > 0, \frac{r^{\delta}}{\delta} > 0, \ \theta_1, \theta_2, \theta_3, \varphi \ \epsilon \ and \ \mu, \eta \ , \delta \ \epsilon \ (0,1]$.

This review demonstrates that triple integral transforms constitute a comprehensive analytical framework for solving three-dimensional mathematical problems.

Variations in kernel structure, integration intervals, and parameter configurations lead to differences in analytical efficiency and domain of application.

The selection of an appropriate transform depends on the nature of the differential equation, boundary conditions, and physical interpretation of the model. [19]

Future research is expected to focus on developing generalized and adaptable triple transforms, as well as integrating them with numerical techniques to achieve hybrid analytical-computational solutions.

Definition (2.12), [20]

Triple SEE Shehu Sadik Transform of the function $f(z, t, x)$ be a continuous function of three variables $z, t, x > 0$ is denoted by

$S_z S_t S_x[f(z, t, x)] = F(\sigma, v, \delta, \mu)$ and defined as :

$$S_z S_t S_x[f(z, t, x)] = F(\sigma, v, \delta, \mu) = \frac{1}{\sigma^n v^{\beta}} \int_0^{\infty} \int_0^{\infty} \int_0^{\infty} e^{-\left(\sigma z + v^{\alpha} + \frac{\delta}{\mu} x\right)} f(z,t,x) dzdtdx.$$

$$= \lim_{\substack{a\to\infty \\ b\to\infty \\ c\to\infty}} \frac{1}{\sigma^n v^\beta} \int_0^\infty \int_0^\infty \int_0^\infty e^{-\left(\sigma z+v^\alpha+\frac{\delta}{\mu}x\right)} \; f(z,t,x)dzdtdx.$$

Where μ , δ , σ and $v > 0$ It converges if the limit of the integral exists , and diverges if not.

The inverse triple SEE Shehu Sadik transform technique of a function $F(\sigma , v, \delta , \mu \ )$ is given by

$$S_z^{-1}S_t^{-1}S_x^{-1}\,[F(\sigma , v, \delta , \mu \ )] = f(z,t,x)$$

Equivalently,

$$f(z,t,x) = S_z^{-1}S_t^{-1}S_x^{-1}\,[F(\sigma , v, \delta , \mu \ )]$$
$$= \frac{1}{2\pi i}\int_{a-i\infty}^{a+i\infty} e^{\alpha\, z} d\sigma \; \frac{1}{2\pi i}\int_{b-i\infty}^{b+i\infty} e^{\alpha\, t} dt \; \frac{1}{2\pi i}\int_{c-i\infty}^{c+i\infty} e^{\frac{\delta}{\mu}x} \; F(\sigma , v, \delta , \mu \ )d\delta.$$

Where a , b and c are real constants.

3. Conclusion

Triple integral transforms represent a unifying and adaptable analytical framework for the solution of 3D PDEs arising in physics, engineering and applied mathematics, as this review shows. In conclusion, to our knowledge, this study provides the first comparative overview of widely used integrals and transforms prevalent in several mathematical disciplines (including triple Laplace, Fourier, Aboodh, Shehu, Ezaki, g-transforms, and a variety of hybrid variants thereof) that shows most of these transforms are closely related because they retain several key defining constructs such as linearity and a transformation from differential operators to algebraic operators; however, they also diverge significantly in their kernel structure, conditions for convergence, dependence on parameters, and domains of applicability. The primary conclusion of the investigation is that the efficiency with which a transform triplet operates is dictated to a large degree by the form of the governing equation and the corresponding boundary or initial conditions, and thus that choosing an appropriate transform is critical for optimal analytical performance. These results are also relevant for higher math modeling because they can minimize the strain on programming and improve the terms needed to identify precise or semi-precise solutions. In addition, the comparative study can highlight how the well-known generalized and mixed transforms are becoming increasingly useful for complex multidimensional systems. Directions for future research include formulation of unified generalized frameworks, enhancement of theoretical attributes like stability and inverse methods, and combination of triple integral transforms with numerical and computational approaches for hybrid analytical–computational modeling.

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