



An Alternative Method to Solve Laguerre and Hermite Differential Equations

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ABSTRACT

The fact that differential equations have an essential role in modelling many problems in various scientific fields such as mathematics, physics, astronomy and engineering, has led to the proposal of new techniques to solve these equations in the fastest and most effective way. Sometimes, the calculations to required to find the solutions of differential equations can be very complex and ultimately tedious. Integral transform methods have been a good way for solving differential equations more easily and accurately. The appropriate choice of an integral transform helps convert a differential equation into an easily solved algebraic equation. In this paper, we introduced an alternative method called the Mohand transform to solve Laguerre and Hermite differential equations. We have found that the proposed method is easy to apply, understandable and accurate.

1. Introduction

The mathematical method of transforming a differential equation into an algebraic equation is called an integral transform and this process is suitable for converting a complex problem into a simpler one. It can convert a function from a domain where some mathematical operations are quite difficult to another domain where they become easier and smoother. The French mathematician and physicist Laplace introduced the Laplace transform (Laplace, 1820). Fourier suggested the Fourier

transform (Bochner & Chandrasekharan, 1949). Fourier and Laplace transforms form the basis of operational analysis which has powerful applications not only in applied mathematics but also in other disciplines such as biology, medicine, mechanics and astronomy.

In recent years, researchers have been eager to use existing integral transforms and to develop new ones for different application areas of life. Until now, many different integral transform methods have been proposed, and most of them have been named after

the people who introduced them. In 2008, Khan and Khan (Khan & Khan, 2008) introduced the N-transform similar to Laplace and Sumudu transforms. In 2011, Elzaki (Elzaki, 2011) introduced the Elzaki Transform derived from the classical Fourier integral. In 2015, Srivastava et al. (Srivastava et al., 2015) explained the M-transform. In 2016, Yang (Yang, 2016) presented a new integral transform that differs from the Laplace, Elzaki and Sumudu transforms. The purpose of his paper was to propose a new integral transform method to find solutions to differential equations in steady heat transfer problem. In 2018, Özkan and Kurt (Özkan & Kurt, 2018) proposed the conformable double Laplace transform, which can be used to solve fractional partial differential equations. Furthermore, in 2018, Aggarwal et al. (Aggarwal et al., 2018) found the Mohand transform of Bessel' functions. They noted that the Mohand transform can be applied to solve Bessel's differential equations. In 2019, Maitama and Zhao (Maitama & Zhao, 2019) used a Laplace type integral transform called the Shehu transform. In 2020, the Rohit transform was proposed by Gupta (Gupta, 2020). Also, Saadeh et al. (Saadeh et al., 2020) suggested a new type of integral transform called the ARA integral transform. Saadeh et al. (2020) proved some properties of the ARA transform and gave some applications of ordinary differential equations to demonstrate the efficiency and high accuracy of it.

However, in 2021, Kushare transform was proposed by Kushare et al. (Kushare et al., 2021) for solving linear ordinary differential equations. Patil (Patil, 2021) explained the applications of the Mahgoub and Aboodh transforms in solving boundary value problems involving systems of ordinary differential equations. The conclusions showed that these transforms were closely related to each other. Katre and Katre (Katre & Katre, 2021) discussed Kamal and Laplace transforms through some of their important properties, inverse transforms of some elementary functions, Kamal and Laplace transforms of the derivatives, Kamal and Laplace transforms of integrals. Also, Sornkaew and Phollamat (Sornkaew & Phollamat, 2021) presented solutions to partial differential equations using the Mohand transform. They gave examples to demonstrate that the method is precise and effective. Kuffi and Abbas (Kuffi & Abbas, 2021) described the properties of integral transforms according to the chronology of their emergence from the oldest to the most recent. In 2022, Rashdi (Rashdi, 2022) explained the Anuj transform to solve ordinary differential equations with variable coefficients. Kuffi and Maktoof (Kuffi & Maktoof, 2022) proposed the Emad-Falih transform method. Patil et al. (Patil et al., 2022)

applied the Anuj transform to solve linear Volterra integral equations. Furthermore, the complex SEE transform was explained by Mansour et al. (Mansour et al., 2022) through numerical problems to solve Abel's integral equation.

Besides these, in 2023, Aggarwal et al. (Aggarwal et al., 2023) used the newly improved integral transform called the Rishi Transformation. Almadry et al. (Almadry et al., 2023) introduced the Iman transform. They proposed that the Iman transform can be used effectively to solve ordinary differential equations, systems of ordinary differential equations and partial differential equations. Mushttt and Kuffi (Mushttt & Kuffi, 2023) compared the complex Sadiq transform and the Sadiq transform to solve the systems of ordinary differential equations. The results showed that the Sadiq and complex Sadiq transforms were closely connected. Also, in 2023, Fadhil and Alkfari (Fadhil & Alkfari, 2021) used the HY transform to obtain the solutions to Linear Volterra integral equations. In 2024, Mansour and Kuffi (Mansour & Kuffi, 2024) proposed a new type of integral transform named the Mayan transform which involves complex powers of a parameter. Saadeh et al. (Saadeh et al., 2024) explained the Mohanad transform along with its fundamental qualities and they used the Mohanad transform to solving systems of ordinary differential equations. Kumawat et al. (Kumawat et al., 2024) introduced the Khalouta transform with numerical examples to confirm the applicability and accuracy of the method. Turab et al. (Turab et al., 2024) suggested the Rishi transform to obtain the analytic solutions of higher-order fractional differential equations. However, in 2025, Mlaki et al. (Mlaki et al., 2025) explored the duality relations of the Shehu transform with other integral transforms to solve linear and non-linear fractional order differential equations. Georgieva et al. (Georgieva et al., 2025) introduced a new approach to solving advection-diffusion equations in 2025. Also, Yazıcı et al. (Yazıcı et al., 2025) proposed a quantative weighted Jafari transform.

2. Preliminaries Notions and Results

The Mohand transform, an alternative method to solve Laguerre and Hermite differential equations, was introduced by Mohand and Mahgoub (Mohand & Mahgoub, 2017). Throughout this paper, K will denote either the real field R or the complex field C . A function $f: (0, \infty) \rightarrow K$ is said to be of exponential order.

The Mohand transform is defined in the set B by

$$B = \left\{ f(x): (0, \infty) \rightarrow K \exists M, k_1, k_2 > 0, |f(x)| < Me^{\frac{|x|}{k_j}}, \text{ if } x \in (-1)^j \times (0, \infty) \right\}$$

where k_j ($j = 1, 2$) can be finite or infinite and the constant M is a finite number (Sornkaew & Phollamat, 2021).

Definition 1. The Mohand transform of function $f(x)$ in B is defined by

$$M\{f(x)\} = R(v) = v^2 \int_0^\infty e^{-vx} f(x) dx \quad (1)$$

where $x \geq 0, k_1 \leq v \leq k_2$ (Mohand & Mahgoub, 2017).

The Mohand transform for the function $f: (0, \infty) \rightarrow K$ exists if $f(x)$ is piecewise continuous and of exponential order (Jung et al., 2021). These conditions are the only sufficient conditions for the existence of the Mohand transform of the function $f(x)$.

Definition 2. Let $R(v)$ is the Mohand transform of a function f , then f is called the inverse Mohand transform of $R(v)$ and it is expressed as

$$M^{-1}\{R(v)\} = f(x) \quad (2)$$

where M^{-1} is the inverse Mohand operator.

Theorem 1. The Mohand transform $M\{f(x)\}$ exists if integral $\int_0^b |f(x)| dx$ exists for any $b > 0$.

Proof. We assume that $v > \frac{1}{k_j}, v > 0$ for sufficiently large v . If we break the integral $v^2 \int_0^\infty e^{-vx} |f(x)| dx$ into two integrals, one from 0 to n and the other from n to ∞ , we obtain

$$\begin{aligned} v^2 \int_0^\infty e^{-vx} |f(x)| dx &= v^2 \int_0^n e^{-vx} |f(x)| dx + v^2 \int_n^\infty e^{-vx} |f(x)| dx, \\ &\leq v^2 \int_0^n |f(x)| dx + v^2 \int_n^\infty e^{-vx} |f(x)| dx, \\ &\leq v^2 \int_0^n |f(x)| dx + v^2 \int_n^\infty e^{-vx} Me^{\frac{|x|}{k_j}} dx, \end{aligned}$$

$$\begin{aligned} &\leq v^2 \int_0^n |f(x)| dx + v^2 M \left[\frac{e^{\left(\frac{1}{k_j} - v\right)x}}{\frac{1}{k_j} - v} \right]_n^\infty, \\ &\leq v^2 \int_0^n |f(x)| dx + v^2 M \left[\frac{e^{\left(\frac{1}{k_j} - v\right)n}}{\frac{1}{k_j} - v} \right]. \end{aligned}$$

The first integral exists by the statement of Theorem 1, and the second term is finite for $v > \frac{1}{k_j}$; hence the Mohand transform $M\{f(x)\}$ exists.

Theorem 2. Let $M\{f(x)\} = R(v)$. Then

$$M\{e^{ax} f(x)\} = \frac{v^2}{(v-a)^2} R(v-a). \quad (3)$$

Proof.

$$\begin{aligned} M\{e^{ax} f(x)\} &= v^2 \int_0^\infty e^{-vx} e^{ax} f(x) dx \\ M\{e^{ax} f(x)\} &= v^2 \int_0^\infty e^{-(v-a)x} f(x) dx \\ M\{e^{ax} f(x)\} &= \frac{v^2}{(v-a)^2} R(v-a). \end{aligned}$$

Let us state the following Theorems (Theorem 3-7) for the Mohand transform of the derivatives. These theorems were proved in (Mohand & Mahgoub, 2017).

Theorem 3. Let $M\{f(x)\} = R(v)$. Then

$$M\{f'(x)\} = vR(v) - v^2 f(0).$$

Theorem 4. Let $M\{f(x)\} = R(v)$. Then

$$M\{f''(x)\} = v^2 R(v) - v^3 f(0) - v^2 f'(0).$$

Theorem 5. Let $M\{f(x)\} = R(v)$. Then

$$M\{xf(x)\} = \left[\frac{2}{v} - \frac{d}{dv} \right] R(v).$$

Theorem 6. Let $M\{f(x)\} = R(v)$. Then

$$M\{xf'(x)\} = 2R(v) - 2vf(0) - \frac{d}{dv} [vR(v) - v^2 f(0)].$$

Theorem 7. Let $M\{f(x)\} = R(v)$. Then

$$M\{xf''(x)\} = 2vR(v) - 2v^2f(0) - 2vf'(0) - \frac{d}{dv}[v^2R(v) - v^3f(0) - v^2f'(0)].$$

Now, in the table below we give the Mohand transform of some elementary functions (Sornkaew & Phollamat, 2021; Verma & Verma, 2023).

Table 1: Mohand transform ($M\{f(x)\}$) of some elementary functions

Function ($f(x)$)	Mohand transform ($M\{f(x)\}$)
1	v
x^n	$\frac{n!}{v^{n-1}}$
e^{ax}	$\frac{v^2}{v-a}$
$\sin ax$	$\frac{av^2}{v^2+a^2}$
$\cos ax$	$\frac{v^3}{v^2+a^2}$
$\sinh ax$	$\frac{av^2}{v^2-a^2}$
$\cosh ax$	$\frac{v^3}{v^2-a^2}$

Theorem 8. Let $R_1(v), R_2(v), R_3(v), \dots, R_n(v)$ be the Mohand transform of the functions $f_1(x), f_2(x), f_3(x), \dots, f_n(x)$ respectively, then

$$M\{a_1f_1(x) + a_2f_2(x) + a_3f_3(x) + \dots + a_nf_n(x)\} = a_1R_1(v) + a_2R_2(v) + a_3R_3(v) + \dots + a_nR_n(v).$$

where $a_1, a_2, a_3, \dots, a_n$ are arbitrary constants.

Proof. If we use definition (1) and the properties of integral, we can write the following result.

$$M\{a_1f_1(x) + a_2f_2(x) + a_3f_3(x) + \dots + a_nf_n(x)\} = v^2 \int_0^\infty [a_1f_1(x) + a_2f_2(x) + a_3f_3(x) + \dots + a_nf_n(x)] e^{-vx} dx,$$

$$M\{a_1f_1(x) + a_2f_2(x) + a_3f_3(x) + \dots + a_nf_n(x)\} = a_1v^2 \int_0^\infty f_1(x) e^{-vx} dx + a_2v^2 \int_0^\infty f_2(x) e^{-vx} dx + a_3v^2 \int_0^\infty f_3(x) e^{-vx} dx + \dots + a_nv^2 \int_0^\infty f_n(x) e^{-vx} dx,$$

$$M\{a_1f_1(x) + a_2f_2(x) + a_3f_3(x) + \dots + a_nf_n(x)\} = a_1R_1(v) + a_2R_2(v) + a_3R_3(v) + \dots + a_nR_n(v)$$

3. Solutions of Laguerre and Hermite Differential Equations

In this section, we first explain the definitions of the Laguerre and Hermite differential equations and give solutions of Laguerre and Hermite differential equations (Koranga et al., 2021; Zwillinger, 1997) and then we compare our solutions with those obtained using the Mohand transform.

Definition 3. The Laguerre differential equation is given as

$$xy'' + (1-x)y' + ny = 0, n \in N. \tag{4}$$

We can obtain the complementary function of equation (4) by using frobenius series (Koranga et al., 2021)

$$y = \sum_{k=0}^\infty a_k x^{k+p}. \tag{5}$$

Taking the derivatives of (5), we get

$$y' = \sum_{k=0}^\infty a_k(k+p)x^{k+p-1},$$

$$y'' = \sum_{k=0}^\infty a_k(k+p)(k+p-1)x^{k+p-2}.$$

If we put the derivatives into (4) and multiply the last equation by x^{-p+1} we get

$$\sum_{k=0}^\infty a_k x^k [(k+p)(k+p)] - (k+p-n) \sum_{k=0}^\infty a_k x^{k+1} = 0. \tag{6}$$

Taking the x^0 coefficient of (6), we find

$$p^2 = 0. \tag{7}$$

Making (6) in x^k by replacing $k \rightarrow k - 1$ in the second term, we obtain

$$\sum_{k=0}^{\infty} x^k [(k+p)(k+p)a_k - (k-1+p-n)a_{k-1}] = 0. \tag{8}$$

(8) requires that each coefficient of x^k vanishes. For this reason we get

$$(k+p)(k+p)a_k - (k-1+p-n)a_{k-1} = 0.$$

If we put the root of (7), $p = 0$ in the above equation, we find the recurrence relation as follows

$$a_k = \frac{(k-1-n)}{k^2} a_{k-1}, \quad k = 1, 2, 3, \dots \tag{9}$$

The explicit form of (5) can be written as

$$y(x) = a_0 + a_1x + a_2x^2 + a_3x^3 + a_4x^4 + a_5x^5 + \dots \tag{10}$$

Putting the value of a_k in (10) and choosing the values of $a_0 = 1$, we get

$$y(x) = \left(1 - nx + \frac{n(n-1)}{(2!)^2} x^2 - \frac{n(n-1)(n-2)}{(3!)^2} x^3 + \frac{n(n-1)(n-2)(n-3)}{(4!)^2} x^4 - \dots \right). \tag{11}$$

Theorem 9. Let $M\{y(x)\} = R(v)$. Then the solution of equation (4) is obtained as

$$y(x) = M^{-1}\{R(v)\} = (-1)^n L_n(x) \tag{12}$$

where $L_n(x) = \frac{e^x}{n!} \frac{d^n}{dx^n} (x^n e^{-x})$.

Here $L_n(x)$ is called the Laguerre polynomial.

Proof. Taking the Mohand transform of (4), we get

$$M\{xy'' + (1-x)y' + ny\} = 0,$$

From Theorem (8), we write

$$M\{xy''\} + M\{y'\} - M\{xy'\} + nM\{y\} = 0$$

Now, from Theorem 3, Theorem 6 and Theorem 7 of the Mohand transform of the derivatives, we write

$$2vR(v) - 2v^2y(0) - 2vy'(0) - \frac{d}{dv} [v^2R(v) - v^3y(0) - v^2y'(0)] + vR(v) - v^2y(0) - 2R(v) - 2vy(0) + \frac{d}{dv} [vR(v) - v^2y(0)] + nR(v) = 0.$$

After necessary simplifications and arrangements we find

$$R'(v)(v-v^2) + R(v)(v-1+n) = 0,$$

$$\frac{R'(v)}{R(v)} = \frac{1-v-n}{v(1-v)},$$

$$\frac{R'(v)}{R(v)} = \frac{1-n}{v} - \frac{n}{1-v}.$$

Taking integral, we get

$$R(v) = \frac{(1-v)^n}{v^{n-1}}. \tag{13}$$

We find the solutions of (4) for $n = 0, 1, 2, 3, \dots$ for $n = 0$, $R(v) = v$ then

$$y(x) = M^{-1}\{v\} = 1 = (-1)^0 L_0(x),$$

for $n = 1$, $R(v) = 1 - v$ then

$$y(x) = M^{-1}\{1 - v\} = x - 1 = (-1)^1 L_1(x),$$

for $n = 2$, $R(v) = \frac{1}{v} - 2 + v$ then

$$y(x) = M^{-1}\left\{\frac{1}{v} - 2 + v\right\} = \frac{1}{2!} (x^2 - 4x + 2) = (-1)^2 L_2(x),$$

for $n = 3$, $R(v) = \frac{1}{v^2} - \frac{3}{v} + 3 - v$ then

$$y(x) = M^{-1}\left\{\frac{1}{v^2} - \frac{3}{v} + 3 - v\right\} = \frac{1}{3!} (x^3 - 9x^2 + 18x - 6) = (-1)^3 L_3(x),$$

for $n \geq 3$, $R(v) = \frac{(1-v)^n}{v^{n-1}}$ then

$$y(x) = M^{-1}\{R(v)\} = (-1)^n L_n(x).$$

Definition 4. The Hermite differential equation is given as

$$y'' - 2xy' + 2ny = 0, \quad n \in N \tag{14}$$

We can obtain the complementary function of equation (14) by using power series (Koranga et al., 2021)

$$y = \sum_{k=0}^{\infty} a_k x^k. \tag{15}$$

Taking the derivatives of (15), we get

$$y' = \sum_{k=0}^{\infty} a_k k x^{k-1}$$

$$y'' = \sum_{k=0}^{\infty} a_k k(k-1) x^{k-2}.$$

Putting the derivatives into (14), we write (20)

$$\sum_{k=0}^{\infty} a_k k(k-1)x^{k-2} - 2 \sum_{k=0}^{\infty} a_k kx^k + 2n \sum_{k=0}^{\infty} a_k x^k = 0. \tag{16}$$

Since the solution $y(x)$ has two solutions that are $y_1(x)$ and $y_2(x)$, we write

Making (16) in x^k by replacing $k \rightarrow k + 2$, we obtain

$$y_1(x) = x + \frac{2(1-n)}{3!}x^3 + \frac{2^2(3-n)(1-n)}{5!}x^5 + \dots \tag{21}$$

$$\sum_{k=0}^{\infty} x^k [(k+1)(k+2)a_{k+2} + (2n-k)a_k] = 0. \tag{17}$$

$$y_2(x) = 1 - \frac{2n}{2!}x^2 - \frac{2^2(2-n)n}{4!}x^4 - \frac{2^3(4-n)(2-n)n}{6!}x^6 + \dots \tag{22}$$

(17) requires that each coefficient of x^k vanishes. For this reason we obtain the following recurrence relation

where $y_1(x)$ is named the odd function and $y_2(x)$ is named the even function. Both $y_1(x)$ and $y_2(x)$ are basic solutions of (14).

$$a_{k+2} = \frac{2(k-n)}{(k+1)(k+2)}a_k, \quad k = 0, 1, 2, 3, \dots \tag{18}$$

In the table below we give the values of solutions $y_1(x)$ and $y_2(x)$ for $n = 0, 1, 2, 3$.

The explicit form of (15) can be written as

$$y(x) = a_0 + a_1x + a_2x^2 + a_3x^3 + a_4x^4 + \dots \tag{19}$$

Putting the values of a_k in (18) and choosing the values of $a_0 = 1$ and $a_1 = 1$, we get

$$y(x) = a_0 \left(1 - \frac{2n}{2!}x^2 - \frac{2^2(2-n)n}{4!}x^4 \dots \right) + a_1 \left(x + \frac{2(1-n)}{3!}x^3 + \dots \right).$$

Table 2: Solutions of Hermite differential equation for $n = 0, 1, 2, 3$.

n	Solution	$y(0)$	$y'(0)$
0	$y_2(x) = 1$	1	0
1	$y_1(x) = x$	0	1
2	$y_2(x) = 1 - 2x^2$	1	0
3	$y_1(x) = x - \frac{2}{3}x^3$	0	1

Now, we obtain solutions using the Mohand transform.

$$M\{y''\} - 2M\{xy'\} + 2nM\{y\} = 0$$

Taking the Mohand transform of (14), we get

From Theorem 3, Theorem 6 and Theorem 7 of the Mohand transform of derivatives, we write

$$M\{y'' - 2xy' + 2ny\} = 0,$$

$$v^2R(v) - v^3y(0) - v^2y'(0) - 2\left\{2R(v) - 2vy(0) - \frac{d}{dv}[vR(v) - v^2y(0)]\right\} + 2nR(v) = 0$$

From Theorem (8), we write

After the necessary simplifications and arrangements we get

$$2vR'(v) + (v^2 - 2 + 2n)R(v) = v^3y(0) + v^2y'(0). \tag{23}$$

Then, we find the solution of (23) and we show the results in the table below.

Table 3: Solutions of Hermite differential equation using Mohand transform for $n = 0, 1, 2, 3$

n	Equation	Solution	$y(x)$
0	$2R'(v) + \left(v - \frac{2}{v}\right)R(v) = v^2$	1	0
1	$2R'(v) + vR(v) = v$	0	1
2	$2R'(v) + \left(v + \frac{2}{v}\right)R(v) = v^2$	1	0
3	$2R'(v) + \left(v + \frac{4}{v}\right)R(v) = v$	0	1

4. Conclusions

In this research, the proposed alternative Mohand transform method is used for the first time to solve Laguerre and Hermite differential equations. The Mohand transform method converts these equations into first order differential equations. So the solution function is easily obtained without lengthy calculations. Also, the comparison of results demonstrate the accuracy of the solutions. In the future, different integral transforms will be proposed to solve these equations, and the consistency of the results will be evaluated.

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