مجـلة الـتربـوي
Journal of Educational
ISSN: 2011- 421X
Arcif Q3

معامل التأثير العربي 1.5
العدد 20

مجلة التربوي

مجلة علمية محكمة تصدر عن كلية التربية

جامعة المرقب

العدد العشرون

يناير 2022م

هيئـــة تحريـر

مجلة التربوي

- المجلة ترحب بما يرد عليها من أبحاث وعلى استعداد لنشرها بعد التحكيم .
- المجلة تحترم كل الاحترام آراء المحكمين وتعمل بمقتضاها .
- كافة الآراء والأفكار المنشورة تعبر عن آراء أصحابها ولا تتحمل المجلة تبعاتها .
- يتحمل الباحث مسؤولية الأمانة العلمية وهو المسؤول عما ينشر له .
- البحوث المقدمة للنشر لا ترد لأصحابها نشرت أو لم تنشر .

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ضوابط النشر:

يشترط في البحوث العلمية المقدمة للنشر أن يراعى فيها ما يأتي :

- أصول البحث العلمي وقواعده .
- ألا تكون المادة العلمية قد سبق نشرها أو كانت جزءا من رسالة علمية .
- يرفق بالبحث تزكية لغوية وفق أنموذج معد .
- تعدل البحوث المقبولة وتصحح وفق ما يراه المحكمون .
- التزام الباحث بالضوابط التي وضعتها المجلة من عدد الصفحات ، ونوع الخط ورقمه ، والفترات الزمنية الممنوحة للتعديل ، وما يستجد من ضوابط تضعها المجلة مستقبلا .

تنبيهات :

- للمجلة الحق في تعديل البحث أو طلب تعديله أو رفضه .
- يخضع البحث في النشر لأولويات المجلة وسياستها .
- البحوث المنشورة تعبر عن وجهة نظر أصحابها ، ولا تعبر عن وجهة نظر المجلة .

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معامل التأثير العربي 1.5
العدد 20

A New Application of Sawi Transform for Solving Ordinary differential equations with Variable Coefficients

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الملخص: في هذه الورقة، طبقنا تحويل تكاملي جديد (تحويل ساوي) لحل بعض المعادلات التفاضلية العادية ذات معاملات متغيرة.

كلمات مفتاحية: تحويل ساوي، المعادلات التفاضلية العادية ذات معاملات متغيرة.

Abstract: In this paper, a new integral transform was applied to solve ordinary differential equations with variable coefficients.

Keywords: *Sawi Transform, Ordinary Differential Equations with variable coefficients.*

Introduction: Ordinary differential equations (ODE) are one of the most important fields of mathematical sciences, especially applied mathematics. They have many types including ODE with constant coefficients and ODE with variable coefficients. These days, ODE with variable coefficients are widely used in astronomy, physics and engineering mathematics [6]. Sometimes, solving this type of equations is complicated but integral transforms play a big role in solving such equations [1], [4] & [5]. In addition to that, integral transforms have become an important tool to deal with problems in applied mathematics, theoretical mechanics, statistics, mathematical physics and pharmacokinetics [4], [5] & [6]. The most important attraction of these transforms is providing the analytical and exact solution of the problem without complicated calculations. Recently, Mahgoub in [1] introduced a new integral transform called Swai transform.

The main purpose of this paper is to show the applicability and efficiency of this transform for solving some ordinary differential equations with variable coefficients.

1. DEFINITION OF SAWI TRANSFORM [1], [2], [3] & [7]

If we have a real function $(t); t \geq 0$, then Sawi Transform is known as proposed in [1] by the following integral equation:

$$S\{G(t)\} = \frac{1}{p^2}\int_0^\infty G(t)e^{-\frac{t}{p}}dt = g(p). \quad (1)$$

Here, S is called the Sawi Transform operator and p is real parameter. The Sawi transform of the function $G(t)$ for $t \geq 0$ work out if $G(t)$ is piecewise continuous and of exponential order. These two conditions are the only sufficient conditions for the existence of Sawi Transform of the function $G(t)$.

2. Sawi Transform and Inverse Sawi Transform of Some Functions [2]

Table (1): Sawi transform and inverse Sawi transform of some functions.

S. No.	$G(t)$	$S\{G(t)\} = g(p)$	$g(p)$	$G(t) = S^{-1}\{g(p)\}$
1	1	$\frac{1}{p}$	$\frac{1}{p}$	1
2	t	1	1	t
3	t^2	$2!\,p$	p	$\frac{t^2}{2!}$
4	$t^n\,; n \in N$	$n!\,p^{n-1}$	$p^{n-1};\ n \in N$	$\frac{t^n}{n!}$
5	$t^n\,; n > -1$	$\Gamma(n+1)p^{n-1}$	$p^{n-1}; n > -1$	$\frac{t^n}{\Gamma(n+1)}$
6	e^{at}	$\frac{a}{p(1-ap)}$	$\frac{a}{p(1-ap)}$	e^{at}
7	$sin\,sin\,at$	$\frac{a}{1+a^2p^2}$	$\frac{1}{1+a^2p^2}$	$\frac{sin\,sin\,at}{a}$
8	$cos\,cos\,at$	$\frac{1}{p(1+a^2p^2)}$	$\frac{1}{p(1+a^2p^2)}$	$cos\,cos\,at$
9	$sinh\,sinh\,at$	$\frac{a}{1-a^2p^2}$	$\frac{1}{1-a^2p^2}$	$\frac{sinh\,sinh\,at}{a}$
10	$cosh\,cosh\,at$	$\frac{1}{p(1-a^2p^2)}$	$\frac{1}{p(1-a^2p^2)}$	$cosh\,cosh\,at$
11	$t^n e^{at}; n \in N$	$\frac{n!\,p^{n-1}}{(1-ap)^{n+1}}$	$\frac{p^{n-1}}{(1-ap)^{n+1}}$	$\frac{1}{n!}t^n e^{at}$

3. Fundamental Properties of Sawi Transform [2]

Table (2): fundamental properties of Sawi Transform.

S. No.	The Property	Mathematical Form
1	Linearity	$S\{lG_1(t)+mG_2(t)\}=lS\{G_1(t)\}+mS\{G_2(t)\}$
2	Change of Scale	$S\{G(at)\}=ag(ap)$
3	Shifting	$S\{e^{at}G(t)\}=\left(\frac{1}{1-ap}\right)^2 g\left(\frac{p}{1-ap}\right)$
4	First Derivative	$S\{G'(t)\}=\frac{1}{p}g(p)-\frac{1}{p^2}G(0)$
5	Second Derivative	$S\{G''(t)\}=\frac{1}{p^2}g(p)-\frac{1}{p^3}G(0)-\frac{1}{p^2}G'(0)$
6	nth Derivative	$S\{G^{(n)}(t)\}=\frac{1}{p^n}g(p)-\frac{1}{p^{n+1}}G(0)-\frac{1}{p^n}G'(0)$ $-\cdots-\frac{1}{p^2}G^{(n)}(0).$
7	Convolution	$S\{G_1(t)*G_2(t)\}=p^2S\{G_1(t)\}S\{G_2(t)\}$

1. Sawi Transform of the Function $tG(t)$ & $t^2G(t)$:

If $S\{G(t)\}=g(p)$ then:

i. $S\{tG(t)\}=p^2\frac{d}{dp}g(p)+2pg(p)$.

Proof. Since, $S\{G(t)\}=\frac{1}{p^2}\int_0^\infty G(t)e^{-\frac{t}{p}}dt=g(p)$

$$\therefore \frac{d}{dp}g(p)=\frac{d}{dp}\left(\frac{1}{p^2}\int_0^\infty G(t)e^{-\frac{t}{p}}dt\right)$$

$$=\frac{-2}{p^3}\int_0^\infty G(t)e^{-\frac{t}{p}}dt+\frac{1}{p^2}\int_0^\infty \frac{t}{p^2}G(t)e^{-\frac{t}{p}}dt$$

$$=\frac{-2}{p}g(p)+\frac{1}{p^2}S\{tG(t)\}$$

$$\Rightarrow S\{tG(t)\}=p^2\frac{d}{dp}g(p)+2pg(p)=\frac{d}{dp}[p^2g(p)]. \qquad (2)$$

ii. $S\{t^2G(t)\}=p^2\left[p^2\frac{d^2}{dp^2}g(p)+6p\frac{d}{dp}g(p)+6g(p)\right].$

Proof. Since, $S\{tG(t)\}=p^2\frac{d}{dp}g(p)+2gp(p)$, so putting $tG(t)$ instead of $G(t)$ yields:

$S\{t.tG(t)\} = p^2 \frac{d}{dp} S\{tG(t)\} + 2pS\{tG(t)\}$

$= p^2 \frac{d}{dp}\left[p^2 \frac{d}{dp} g(p) + 2pg(p)\right] + 2p\left[p^2 \frac{d}{dp} g(p) + 2pg(p)\right]$

$= p^4 \frac{d^2}{dp^2} g(p) + 2p^3 \frac{d}{dp} g(p) + 2p^3 \frac{d}{dp} g(p) + 2p^2 g(p) + 2p^3 \frac{d}{dp} g(p) + 4p^2 g(p)$

$= p^4 \frac{d^2}{dp^2} g(p) + 6p^3 \frac{d}{dp} g(p) + 6p^2 g(p)$

$\therefore\ S\{t^2 G'(t)\} = p^2\left[p^2 \frac{d^2}{dp^2} g(p) + 6p \frac{d}{dp} g(p) + 6g(p)\right].$ (3)

2. Sawi Transform of the Functions $tG'(t)$ & $t^2G'(t)$:

If $S\{G(t)\} = g(p)$ then:

i. $S\{tG'(t)\} = p \frac{d}{dp} g(p) + g(p) - \frac{d}{dp} G(0).$

Proof. Since, $S\{G'(t)\} = \frac{1}{p} g(p) - \frac{1}{p^2} G(0)$, so in (2) put $G'(t)$ instead of $G(t)$, therefore:

$S\{tG'(t)\} = p^2 \frac{d}{dp} S\{G'(t)\} + 2pS\{G'(t)\}$

$= p^2 \frac{d}{dp}\left[\frac{1}{p} g(p) - \frac{1}{p^2} G(0)\right] + 2p\left[\frac{1}{p} g(p) - \frac{1}{p^2} G(0)\right]$

$= p^2\left[-\frac{1}{p^2} g(p) + \frac{1}{p}\frac{d}{dp} g(p) + \frac{2}{p^3} G(0) - \frac{1}{p^2}\frac{d}{dp} G(0)\right] + 2g(p) - \frac{2}{p} G(0)$

$= -g(p) + p \frac{d}{dp} g(p) - \frac{d}{dp} G(0) + 2g(p)$

$\therefore S\{tG'(t)\} = p \frac{d}{dp} g(p) + g(p) - \frac{d}{dp} G(0) = \frac{d}{dp}[pg(p) - G(0)].$ (4)

ii. $S\{t^2G'(t)\} = p\left[p^2 \frac{d^2}{dp^2} g(p) + 4p \frac{d}{dp} g(p) + 2g(p)\right] - \frac{d}{dp}\left[p^2 \frac{d}{dp} G(0)\right].$

Proof. In the same way as before, we get:

$S\{t.tG'(t)\} = p^2 \frac{d}{dp} S\{tG'(t)\} + 2pS\{tG'(t)\}$

$$= p^2 \frac{d}{dp}\left[p\frac{d}{dp} g(p) + g(p) - \frac{d}{dp} G(0)\right] + 2p\left[p\frac{d}{dp} g(p) + g(p) - \frac{d}{dp} G(0)\right]$$

$$= p^2 \frac{d}{dp} g(p) + p^2 \frac{d}{dp} g(p) + p^3 \frac{d^2}{dp^2} g(p) - p^2 \frac{d^2}{dp^2} G(0) + 2pg(p) + 2p^2 \frac{d}{dp} g(p) - 2p\frac{d}{dp} G(0)$$

$$= 4p^2 \frac{d}{dp} g(p) + p^3 \frac{d^2}{dp^2} g(p) + 2pg(p) - \frac{d}{dp}\left[p^2 \frac{d}{dp} G(0)\right]$$

$\therefore\ S\{t^2 G'(t)\} =$

$$p\left[p^2 \frac{d^2}{dp^2} g(p) + 4p\frac{d}{dp} g(p) + 2g(p)\right] - \frac{d}{dp}\left[p^2 \frac{d}{dp} G(0)\right]. \qquad (5)$$

3. Sawi Transform of the Functions $tG''(t)$ & $t^2 G''(t)$:

If $S\{G(t)\} = g(p)$ then:

i. $S\{tG''(t)\} = \frac{d}{dp} g(p) - \frac{1}{p}\frac{d}{dp} G(0) + \frac{1}{p^2} G(0) - \frac{d}{dp} G'(0).$

Proof. Since, $S\{G''(t)\} = \frac{1}{p^2} g(p) - \frac{1}{p^3} G(0) - \frac{1}{p^2} G'(0)$, therefore in (2) put $tG''(t)$ instead of $G''(t)$ which gives us:

$$S\{tG''(t)\} = p^2 \frac{d}{dp} S\{G''(t)\} + 2pS\{G''(t)\}$$

$$= p^2 \frac{d}{dp}\left[\frac{1}{p^2} g(p) - \frac{1}{p^3} G(0) - \frac{1}{p^2} G'(0)\right] + 2p\left[\frac{1}{p^2} g(p) - \frac{1}{p^3} G(0) - \frac{1}{p^2} G'(0)\right]$$

$$= p^2\left[\frac{1}{p^2}\frac{d}{dp} g(p) - \frac{2}{p^3} g(p) - \frac{1}{p^3}\frac{d}{dp} G(0) + \frac{3}{p^4} G(0) - \frac{1}{p^2}\frac{d}{dp} G'(0) + \frac{2}{p^3} G'(0)\right] + \quad 2p\left[\frac{1}{p^2} g(p) - \frac{1}{p^3} G(0) - \frac{1}{p^2} G'(0)\right]$$

$\therefore\quad S\{tG''(t)\} =$

$$\frac{d}{dp} g(p) - \frac{1}{p}\frac{d}{dp} G(0) + \frac{1}{p^2} G(0) - \frac{d}{dp} G'(0) \qquad (6)$$

ii. $S\{t^2 G''(t)\} = \frac{d}{dp}\left[p^2 \frac{d}{dp} g(p)\right] - \frac{d}{dp}\left[p^2 \frac{d}{dp} G'(0)\right] - p\frac{d^2}{dp^2} G(0).$

Proof. Since, $S\{tG''(t)\} = \frac{d}{dp} g(p) - \frac{1}{p}\frac{d}{dp} G(0) + \frac{1}{p^2} G(0) - \frac{d}{dp} G'(0)$, with the same way as before, we get:

$$S\{t^2 G''(t)\} = p^2 \frac{d}{dp} S\{tG''(t)\} + 2pS\{tG''(t)\}$$

$$= p^2 \frac{d}{dp}\left[\frac{d}{dp} g(p) - \frac{1}{p}\frac{d}{dp} G(0) + \frac{1}{p^2} G(0) - \frac{d}{dp} G'(0)\right] +$$
$$2p\left[\frac{d}{dp} g(p) - \frac{1}{p}\frac{d}{dp} G(0) + \frac{1}{p^2} G(0) - \frac{d}{dp} G'(0)\right]$$
$$= p^2 \frac{d^2}{dp^2} g(p) + 2p\frac{d}{dp} g(p) - p^2\frac{d^2}{dp^2} G'(0) - 2p\frac{d}{dp} G'(0) - p\frac{d^2}{dp^2} G(0)$$

$\therefore S\{t^2 G''(t)\} =$
$$\frac{d}{dp}\left[p^2 \frac{d}{dp} g(p)\right] - \frac{d}{dp}\left[p^2\frac{d}{dp} G'(0)\right] - p\frac{d^2}{dp^2} G(0). \qquad (7)$$

Therefore, we can summarize the above work in table (3):

Table (3): Sawi Transform of other functions.

S. No.	$F(t)$	$S\{F(t)\}$
1	$t^n e^{at}$	$\frac{n!\,p^{n-1}}{(1-ap)^{n+1}}$
2	$tG(t)$	$p^2 \frac{d}{dp} g(p) + 2pg(p)$
3	$t^2G(t)$	$p^2\left[p^2\frac{d^2}{dp^2} g(p) + 6p\frac{d}{dp} g(p) + 6g(p)\right]$
4	$tG'(t)$	$p\frac{d}{dp} g(p) + g(p) - \frac{d}{dp} G(0)$
5	$t^2G'(t)$	$p\left[p^2\frac{d^2}{dp^2} g(p) + 4p\frac{d}{dp} g(p) + 2g(p)\right] - \frac{d}{dp}\left[p^2\frac{d}{dp} G(0)\right]$
6	$tG''(t)$	$\frac{d}{dp} g(p) - \frac{1}{p}\frac{d}{dp} G(0) + \frac{1}{p^2} G(0) - \frac{d}{dp} G'(0)$
7	$t^2G''(t)$	$\frac{d}{dp}\left[p^2\frac{d}{dp} g(p)\right] - \frac{d}{dp}\left[p^2\frac{d}{dp} G'(0)\right] - p\frac{d^2}{dp^2} G(0)$

Note 1: In the same way posed in the previous paragraphs, we can calculate Sawi Transform of functions $t^n G^{(n)}(t)\ ;\ n \in N$.

Applications

Example (1): Solve the differential equation:

$ty'' - ty' - y = 0$

with the initial condition $y(0) = 0\ \&\ y'(0) = 2$.

Solution: Taking Sawi transform to both sides of given equation to give us:

$S\{ty''\} - S\{ty'\} - S\{y\} = 0.$

$\frac{d}{dp}S\{y\} - \frac{1}{p}\frac{d}{dp}y(0) + \frac{1}{p^2}y(0) - \frac{d}{dp}y'(0) - p\frac{d}{dp}S\{y\} - S\{y\} + \frac{d}{dp}y(0) - S\{y\} = 0$

$\Rightarrow \frac{d}{dp}S\{y\}[1-p] - 2S\{y\} = 0$

$\frac{d\,S\{y\}}{S\{y\}} = \frac{2}{1-p}dp \quad \Rightarrow S\{y\} = \frac{C}{(1-p)^2}.$

By applying inverse Sawi transform, we get:

$$y = S^{-1}\left\{\frac{C}{(1-p)^2}\right\} \quad \Rightarrow \quad y = Cte^t.$$

$\because\ y'(0) = 2 \ \Rightarrow C = 2 \quad \Rightarrow \quad y = 2te^t.$

Example (2): Solve the differential equation:

$ty'' + (1-2t)y' - 2y = 0,$

with $[y(0) = 1 \,\&\, y'(0) = 2]$.

Solution: Taking the Sawi transform of given equation to give us:

$S\{ty''\} + S\{(1-2t)y'\} - 2S\{y\} = 0$

$\frac{d}{dp}S\{y\} - \frac{1}{p}\frac{d}{dp}y(0) + \frac{1}{p^2}y(0) - \frac{d}{dp}y'(0) + \frac{1}{p}S\{y\} - \frac{1}{p^2}y(0) - 2\left[p\frac{d}{dp}S\{y\} + S\{y\} - \frac{d}{dp}y(0)\right] - 2S\{y\} = 0$

$\Rightarrow \frac{d}{dp}S\{y\}[1-2p] + S\{y\}\left[\frac{1}{p} - 4\right] = 0.$

Let $R = S\{y\}$

$\Rightarrow \frac{dR}{dp} = -\frac{4p-1}{2p^2-p}R \ \Rightarrow \frac{dR}{R} = -\frac{4p-1}{2p^2-p} \ \Rightarrow R = \frac{c}{p(1-2p)} \equiv S\{y\} = \frac{c}{p(1-2p)}.$

Now applying inverse Sawi transform, we get

$y = S^{-1}\left\{\frac{c}{p(1-2p)}\right\} \Rightarrow y = \frac{c}{2}e^{2t}.$

$\because\ y(0) = 1 \ \Rightarrow 1 = \frac{c}{2} \Rightarrow c = 2 \ \Rightarrow \quad y = e^{2t}.$

Example (3): Solve the differential equation:

$ty'' + y' = 4t^2$

with the initial condition $\quad y(0) = 1 \,\&\, y'(0) = 0.$

Solution: Applying the Sawi transform to both sides of the given equation, we get:

$S\{ty''\} + S\{y'\} = 4S\{t^2\}$

$\frac{d}{dp}S\{y\} - \frac{1}{p}\frac{d}{dp}y(0) + \frac{1}{p^2}y(0) - \frac{d}{dp}y'(0) + \frac{1}{p}S\{y\} - \frac{1}{p^2}y(0) = 8p$

$\Rightarrow \frac{d}{dp}S\{y\} + \frac{1}{p}S\{y\} = 8p\,, \qquad$ suppose $R = S\{y\}$

$\therefore\ \frac{dR}{dp}+\frac{1}{P}R=8p$

which is a linear differential equation and it has the integrative factor: $\lambda=p$.

$\Rightarrow\ R=\frac{8p^2}{3}+\frac{c}{p} \qquad \Rightarrow \quad S\{y\}=\frac{8p^2}{3}+\frac{c}{p}$.

By apply inverse Sawi transform to both sides of last equation, we get

$y=S^{-1}\left\{\frac{8p^2}{3}\right\}+cS^{-1}\left\{\frac{1}{p}\right\} \ \Rightarrow \qquad y=\frac{4t^3}{9}+c$.

$\because\ y(0)=1\ \Rightarrow 1=0+c\Rightarrow c=1\ \Rightarrow\quad y=\frac{4t^3}{9}+1$.

Example (4): Solve the differential equation:

$t^2y''-4ty'+4y=0$

with $[y(0)=0\ \&\ y'(0)=1]$.

Solution: Taking the Sawi transform of given equation to give us:

$S\{t^2y''\}-4S\{ty'\}+4S\{y\}=0$

$p^2\frac{d^2}{dp^2}S\{y\}+2p\frac{d}{dp}S\{y\}-p^2\frac{d^2}{dp^2}y'(0)-2p\frac{d}{dp}y'(0)-p\frac{d^2}{dp^2}y(0)-$
$4\left[p\frac{d}{dp}S\{y\}+S\{y\}-\frac{d}{dp}y(0)\right]+4S\{y\}=0$

$p^2\frac{d^2}{dp^2}S\{y\}-2p\frac{d}{dp}S\{y\}=0$.

Assume $R=S\{y\}$ and then let $W=\frac{dR}{dp}$, so we get

$\Rightarrow\frac{dW}{dp}=\frac{2W}{p}\ \Rightarrow\frac{dW}{W}=2\frac{dp}{p}\ \Rightarrow W=c_1p^2\Rightarrow\frac{dR}{dp}=c_1p^2\Rightarrow R=\frac{c_1p^3}{3}+c_2$

$\Rightarrow S\{y\}=\frac{c_1p^3}{3}+c_2$.

Then apply inverse Sawi transform, we get

$y=\frac{c_1}{3}S^{-1}\{p^3\}+c_2S^{-1}\{1\}\Rightarrow y=\frac{c_1t^4}{3.4!}+c_2t,\ let\ \ y=Ct^4+c_2t;\ C=\frac{c_1}{72}$.

$\because\ y'(0)=1\ \Rightarrow c_2=1\ \Rightarrow\quad y=Ct^4+t$.

Conclusion: In this paper, authors successfully discussed the application of Sawi transform for solving ODE's with variable coefficients by giving four numerical problems. The results of numerical problems show that the Sawi transform is very useful integral transform for solving such equations. At last, all the obtained solutions of the indicated numerical problems are satisfied by putting them back in the corresponding equations. In future, Sawi transform can be used for solving a wide class of similar equations.

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