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New Finite Integrals Involving Product of Modified Multivariable H-function

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Abstract : The aim of the present paper is to study some new finite integrals. We obtain two finite double integrals involving the product of the Modified Multivariable H-function and Srivastava Polynomials. The values of the integrals are obtained in terms of $\Psi(Z)$ (the logarithmic derivative of $\Gamma(z)$). We establish an interesting integral relation in terms of Modified Multivariable *H*-function. Present finding are the most general in nature and act as the key formulas from which we can obtain their special cases.

Keywords : Modified Multi-variable *H*-function, general class of Polynomials, generalized Wright hypergeometric function logarithmic derivative of $\Gamma(z)$.

Introduction : The modified multivariable *H*-function employed as kernel of multi-dimensional transform defined by Prasad and Singh [5] on the lines of Srivastava and Panda [7], Prasad and Maurya [4] is as follows:

$$H^{m,n:|R':m_1,n_1;,\dots;m_r,n_r}_{p,q:|R:p_1,q_1;\dots;p_r,q_r}$$

$$\left[\begin{matrix} z_1 \\ \vdots \\ z_r \end{matrix}\left|\begin{matrix} (a_j;\alpha'_j,\dots,\alpha_j^{(r)})_{1,p}:(e_j;u'_j g'_j,\dots,u_j^{(r)} g_j^{(r)})_{1,IR'}:(c'_j,\gamma'_j)_{1,p_1};\dots;(c_j^{(r)},\gamma_j^{(r)})_{1,p_r} \\ (b_j;\beta'_j,\dots,\beta_j^{(r)})_{1,q}:(l_j;U'_j f'_j,\dots,U_j^{(r)} f_j^{(r)})_{1,IR}:(d'_j,\delta'_j)_{1,q_1};\dots;(d_j^{(r)},\delta_j^{(r)})_{1,q_r} \end{matrix}\right.\right]$$

$$= \frac{1}{(2\pi\omega)^r}\int_{L_1}\cdots\int_{L_r}\Phi\ (\xi_1)\dots\Phi_r(\xi_r)\psi(\xi_1\dots\xi_r)z_1^{\xi_1}\dots z_r^{\xi_r}\,d\xi_1\dots d\xi_r \qquad (1)$$

where

$$\Phi_i(\xi_i) = \frac{\prod_{j=1}^{m_i}\Gamma\left(d_j^{(i)}-\delta_j^{(i)}\xi_i\right)\prod_{j=1}^{n_i}\Gamma\left(1-c_j^{(i)}-\gamma_j^{(i)}\xi_i\right)}{\prod_{j=m_i+1}^{q_i}\Gamma\left(1-d_j^{(i)}+\delta_j^{(i)}\xi_i\right)\prod_{j=n_i+1}^{p_i}\Gamma.\left(c_j^{(i)}-\gamma_j^{(i)}\xi_i\right)} \text{ (i} = 1,2,\ldots,\text{r)} \tag{2}$$

$$\psi(\xi_i,\ldots,\xi_r) = \frac{\prod_{j=1}^{m_i}\Gamma\left(b_j-\sum_{i=1}^{r}\beta_j^{(i)}\xi_i\right)\prod_{j=1}^{n}\Gamma\left(1-a_j+\sum_{i=1}^{r}\alpha_j^{(i)}\xi_i\right)\prod_{j=1}^{R'}\Gamma\left(e_j+\sum_{i=1}^{r}u_j^{(i)}g_j^{(i)}\xi_i\right)}{\prod_{j=m+1}^{p}\Gamma\left(a_j-\sum_{i=1}^{r}\alpha_j^{(i)}\xi_i\right)\prod_{j=n+1}^{q}\Gamma\left(1-b_j+\sum_{i=1}^{r}\beta_j^{(i)}\xi_i\right)\prod_{j=1}^{R}\Gamma\left(l_j+\sum_{i=1}^{r}U_j^{(i)}f_j^{(i)}\xi_i\right)} \tag{3}$$

The multiple integral (1) converges absolutely if

$$|arg z_i| < \frac{1}{2}U_i\pi, \quad \text{(i=1,2,...,r).}$$

where

$$U_i = \sum_{j=1}^{m}\beta_j^{(i)} - \sum_{j=m+1}^{q}\beta_j^{(i)} + \sum_{j=1}^{n}\alpha_j^{(i)} - \sum_{j=n+1}^{p}\alpha_j^{(i)}\sum_{j=1}^{m}\delta_j^{(i)} - \sum_{j=m_1+1}^{q_i}\delta_j^{(i)}\sum_{j=1}^{n_1}\gamma_j^{(i)}$$

$$-\sum_{j=n_i+1}^{p_i}\gamma_j^{(i)} + \sum_{j=1}^{R'}g_j^{(i)} - \sum_{j=1}^{R}f_j^{(i)} > 0 \text{ (i=1,2...,r)} \tag{3 (a)}$$

The Srivastava Polynomials $S_n^m[x]$ will be defined and represented as follows (Srivastava, 1972, Eq.1) [8]

$$s_n^m[x] = \sum_{l=0}^{[n/m]}\frac{(-n)_{ml}}{l!}A_{n,l}x^l \tag{4}$$

where n = 0,1,2 ....m is an arbitrary Positive integer, the co-efficients An, I (n, I >, 0) are arbitrary constants, real or complex.

$S_n^m[x]$ yields number of known Polynomials as its special cases. These include, among other, the Jacobi Polyomials, the Bessel Polynomials, the Brafman Polynomials and several other (Srivastava and Sing, 1983) [10]

The following well known Euler lntegral formula is required to establish the main integral [Srivastava and Karlsson, 1985 Eq.2] [11]

$$\int\int u^{\alpha-1}\, v^{\beta-1}[1-u-v]^{\gamma-1}du\, dv = \frac{\Gamma(\alpha)(\beta)(\gamma)}{\Gamma(\alpha+\beta+\ \gamma)} \tag{5}$$

$$u \geq 0, v \geq 0, u+v \leq 1, R(\alpha) > 0, R(\beta), R(\gamma) > 0$$

Main Integrals:

Let Ψ(z) denote the logarithmic derivative of gamma function Γ(z) i.e. :

$$\Psi(z) = \frac{\Gamma'(\mathrm{z})}{\Gamma(\mathrm{z})}$$

We have

First Integral:

$$\int_0^1\int_0^{1-x} x^{a-1}y^{b-1}(1-x-y)^{c-1}\log(x)\prod_{i=1}^{r} S_{n_i}^{m_i}[c_i x^{u_i}y^{v_i}(1-x-y)^{w_i}]x$$

$$H^{m,n:|R':m_1,n_1;,\ldots;m_r,n_r}_{p,q:|R:p_1,q_1;\ldots.;\ p_r,q_r}\begin{bmatrix} z_1 & x^{u_i}y^{v_i}\left(1-x-y\right)^{w_i} \\ \vdots & \\ z_r & x^{u_r}y^{v_r}\left(1-x-y\right)^{w_r}\end{bmatrix} dxdy$$

$$= \prod_{i=1}^{r}\sum_{l_i=0}^{[n_i|m_i]}\frac{(-n_i)_{m_i l_i}}{l_i!}\,\mathrm{A}_{n_i l_i}\, C_i^{l_i}\sum_{t=0}^{\infty}\sum_{h=1}^{m}\phi_i(\xi_i)$$

$$\frac{\{\Gamma(a+\sum_{i=1}^{r}u_i l_i + u\sum_{i=1}^{r}\xi_i)\}^{l}\{\Gamma(b+\sum_{i=1}^{r}v_i l_i + v\sum_{i=1}^{r}\xi_i)\}^{l}\{\Gamma(C+\sum_{i=1}^{r}w_i l_i + w\sum_{i=1}^{r}\xi_i)\}^{l}}{\{\Gamma(a+b+c+\sum_{i=1}^{r}(u_i+v_i+w_i)\ l_i + (u+v+w)\sum_{i=1}^{r}(\xi_i)\}^{l}}$$

$$z_1^{\xi_1}\ldots z_r^{\xi_r}\left[\Psi\left(a+\sum_{i=1}^{r}u_i l_i + v\sum_{i=1}^{r}\xi_i\right) - \Psi\left\{\mathrm{a}+\mathrm{b}+\mathrm{c}+\sum_{i=1}^{r}(u_i+v_i+w_i)l_i + (u+v+w)\sum_{i=1}^{r}\xi_i\right\}\right] \tag{6}$$

Second Integral:

$$\int_0^1\int_0^{1-x} x^{a-1}y^{b-1}(1-x-y)^{c-1}\log(1-x-y)\prod_{i=1}^{r} S_{n_i}^{m_i}[c_i x^{u_i}y^{v_i}(1-x-y)^{w_i}]x$$

$$H_{p,q:|R:p_1,q_1;....;\,p_r,q_r}^{m,n:|R':m_1,n_1;,...;m_r,n_r}\begin{bmatrix} z_1 & x^{u_i}y^{v_i}(1-x-y)^{w_i} \\ \vdots & \\ z_r & x^{u_r}y^{v_r}(1-x-y)^{w_r}\end{bmatrix} dxdy$$

$$=\prod_{i=1}^{r}\sum_{l_i=0}^{[n_i|m_i]}\frac{(-n_i)_{m_i l_i}}{l_i!}\,\mathrm{A}_{\,n_i l_i}\,C_i^{l_i}\sum_{t=0}^{\infty}\sum_{h=1}^{m}\phi_i(\xi_i)$$

$$\frac{\{\Gamma(a+\sum_{i=1}^{r}u_i l_i+u\sum_{i=1}^{r}\xi_i)\}^l\{\Gamma(b+\sum_{i=1}^{r}v_i l_i+v\sum_{i=1}^{r}\xi_i)\}^l\{\Gamma(C+\sum_{i=1}^{r}w_i l_i+w\sum_{i=1}^{r}\xi_i)\}^l}{\{\Gamma(a+b+c+\sum_{i=1}^{r}(u_i+v_i+w_i)\,l_i+(u+v+w)\sum_{i=1}^{r}(\xi_i)\}^l}$$

$$z_1^{\xi_1}\ldots z_r^{\xi_r}\left[\Psi\left(b+\sum_{i=1}^{r}u_i l_i+v\sum_{i=1}^{r}\xi_i\right)-\Psi\left\{\mathrm{a}+\mathrm{b}+\mathrm{c}+\sum_{i=1}^{r}(u_i+v_i+w_i)l_i+(u+v+w)\sum_{i=1}^{r}\xi_i\right\}\right] \quad (7)$$

Third Integral:

$$\int_0^1\int_0^{1-x} x^{a-1}y^{b-1}(1-x-y)^{c-1}\,log(1-x-y)\prod_{i=1}^{r} S_{n_i}^{m_i}[c_i x^{u_i}y^{v_i}(1-x-y)^{w_i}]x$$

$$H_{p,q:|R:p_1,q_1;....;\,p_r,q_r}^{m,n:|R':m_1,n_1;,...;m_r,n_r}\begin{bmatrix} z_1 & x^{u_i}y^{v_i}(1-x-y)^{w_i} \\ \vdots & \\ z_r & x^{u_r}y^{v_r}(1-x-y)^{w_r}\end{bmatrix} dxdy$$

$$= \prod_{i=1}^{r} \sum_{l_i=0}^{[n_i|m_i]} \frac{(-n_i)_{m_i l_i}}{l_i!} A_{n_i l_i} C_i^{l_i} \sum_{t=0}^{\infty} \sum_{h=1}^{m} \phi_i(\xi_i)$$

$$\frac{\{\Gamma(a+\sum_{i=1}^{r} u_i l_i + u\sum_{i=1}^{r} \xi_i)\}^l \{\Gamma(b+\sum_{i=1}^{r} v_i l_i + v\sum_{i=1}^{r} \xi_i)\}^l \{\Gamma(C+\sum_{i=1}^{r} w_i l_i + w\sum_{i=1}^{r} \xi_i)\}^l}{\{\Gamma(a+b+c+\sum_{i=1}^{r}(u_i+v_i+w_i)\, l_i + (u+v+w)\sum_{i=1}^{r}(\xi_i)\}^l}$$

$$z_1^{\xi_1} \ldots z_r^{\xi_r} \left[\Psi\left(c+\sum_{i=1}^{r} w_i l_i + w\sum_{i=1}^{r} \xi_i\right) - \Psi\left\{a+b+c+\sum_{i=1}^{r}(u_i+v_i+w_i)l_i + (u+v+w)\sum_{i=1}^{r} \xi_i\right\}\right] \quad (8)$$

The following interesting integral will be required to establish the results from eq. 6 to 8.

$$\int_0^1 \int_0^{1-x} x^{a-1} y^{b-1} (1-x-y)^{c-1} \prod_{i=1}^{r} S_{n_i}^{m_i}[c_i x^{u_i} y^{v_i} (1-x-y)^{w_i}] x$$

$$H_{p,q:|R:p_1,q_1;\ldots;\, p_r,q_r}^{m,n:|R':m_1,n_1;,\ldots;m_r,n_r} \begin{bmatrix} z_1 & x^{u_i} y^{v_i}(1-x-y)^{w_i} \\ \vdots & \\ z_r & x^{u_r} y^{v_r}(1-x-y)^{w_r} \end{bmatrix} dxdy$$

$$= \prod_{i=1}^{r} \sum_{l_i=0}^{[n_i|m_i]} \frac{(-n_i)_{m_i l_i}}{l_i!} \mathrm{A}_{n_i l_i} C_i^{l_i} H_{p+3,q+1:|R:p_1 q_1;\ldots\ldots;p_r,q_r}^{m_1 n+3:\,|R':m_1 n_1;\ldots\ldots;m_r,n_r}$$

$$\left[\begin{matrix} z_1 \\ \vdots \\ z_r \end{matrix} \middle| \begin{matrix} (1-a-\sum_{i=1}^{r} u_i l_i, u; l), (1-b-\sum_{i=1}^{r} v_i l_i, v; l)(1-c-\sum_{i=1}^{r} w_i l_i, w; l) \\ \\ (b_j;\, \beta_j', \ldots, \beta_j^{(r)})_{1,q}; (l_j;\, u_j' f_j', \ldots, U_j^{(r)} F_j^{(r)})_{1,|R}; \end{matrix}\right.$$

$$\left.\begin{matrix}(a_j;\alpha_j;A_j)_{1,n'}\,(e_j:u_j'g_j',\ldots u_j^{(r)}g_j^{(r)})_{1,\backslash R'}\,,(C_j',\gamma_j')_{1,p_1};\ldots.;(C_j^{(r)},\gamma_j^{(r)})_{1,P_r}\\ (d_j',\delta_j')_{1,q_1},;\ldots.;(d_j^{(r)},\delta_j^{(r)})_{1,q_r}(1-a-b-c-\sum_{i=1}^{r}(u_i+v_i+w_i)_l,u+v+w;l)\end{matrix}\right] \quad (9)$$

$$=\prod_{i=1}^{r}\sum_{l_i=0}^{[n_i|m_i]}\frac{(-n_i)_{m_il_i}}{l_i!}\,A_{n_il_i}\,C_i^{l_i}\sum_{t=0}^{\infty}\phi_i(\xi_i)x$$

$$\frac{\{\Gamma(a+\sum_{i=1}^{r}u_il_i+u\sum_{i=1}^{r}\xi_i)\}^l\{\Gamma(b+\sum_{i=1}^{r}v_il_i+v\sum_{i=1}^{r}\xi_i)\}^l\{\Gamma(c+\sum_{i=1}^{r}w_il_i+w\sum_{i=1}^{r}\xi_i)\}^l}{\{\Gamma(a+b+c+\sum_{i=1}^{\infty}(u_i+v_i+w_i)l_i+(u+v+w)\sum_{i=1}^{r}\xi_i\}^l}$$

$$z_1^{\xi_1}\ldots\ldots\ldots\ldots\ldots.z_r^{\xi_r} \quad (10)$$

The above result eqn. 9 will be valid under the following conditions.

- $u_i>0,v_i>0,w_i>0,u\geq 0,v\geq 0,w\geq 0$
- $Re\left[a+u\min_{1\geq j\geq m}\left(\frac{b_j}{\beta_j}\right)\right]>0,Re\left[b+v\min_{1\geq j\geq m}\left(\frac{b_j}{\beta_j}\right)\right]>0\ and$

$$Re\left[c+w\min_{1\geq j\geq m}\left(\frac{b_j}{\beta_j}\right)\right]>0$$

- $|\arg z|<\frac{1}{2}\,u\,\pi$

where u is given by eqn. [3(a)]

To evaluate the above integral we express $S_n^m[x]$ in its series from with the help of eqn. 4 and Modified Multivariable *H*-function in terms of Mellin-Barnes type of contour integral [12] by eqn. 1 and then interchanging the order of integration and summation, we get

$$=\prod_{i=1}^{r}\sum_{l_i=0}^{[n_i|m_i]}\frac{(-n_i)_{m_il_i}}{l_i!}\,A_{n_il_i}\,C_i^{l_i}\frac{1}{(2\pi\omega)^r}\int_{L_1}\ldots\int_{L_r}\phi_1(\xi_1)\ldots\phi_r(\xi_r)\Psi(\xi_1,\ldots.\xi_r)z_1^{\xi_1}\ldots z_r^{\xi_r}$$

$$\left[\int_0^1\int_0^{1-x}x^{a+\sum_{i=1}^{r}u_il_i+u\{\xi_1\ldots\xi_r\}-l}\,y^{b+\sum_{i=1}^{r}v_il_i+v\xi_i-l}\,(1-x-y)^{c+\sum_{i=1}^{r}w_il_i+w\xi_i-l}\,dxdy\right]$$

$$d\xi_1\ldots d\xi_r \quad (11)$$

Further using the result eqn. 5 the above integral becomes :

$$= \prod_{i=1}^{r} \sum_{l_i=0}^{[n_i|m_i]} \frac{(-n_i)_{m_i l_i}}{l_i!} \mathrm{A}_{n_i l_i} C_i^{l_i} \frac{1}{(2\pi\omega)^r} \int_{L_1} \dots \int_{L_r} \phi_1(\xi_1) \dots \phi_r(\xi_r) \Psi(\xi_1, \dots . \xi_r) z_1^{\xi_1} \dots z_r^{\xi_r}$$

$$\frac{[\{\Gamma(a + \sum_{i=1}^{r} u_i l_i + u(\xi_1 \dots \xi_r)\}^l \{\Gamma(b + \sum_{i=1}^{r} v_i l_i + v(\xi_1 \dots \xi_r)\}^l \{\Gamma(c + \sum_{i=1}^{r} w_i l_i + w(\xi_1 \dots \xi_r)\}^l]\, d\xi_1, \dots . d\xi_r}{\{\Gamma(a + b + c + \sum_{i=1}^{r}(u_i + v_i + w_i) l_i + (u + v + w)\,(\xi_1, \dots . \xi_r)\}^l} \tag{12}$$

then interpret with the help of eqn. 1 and eqn. 12, we have the required result (eqn. 9) and if we express Modified Multivariable *H*-function in series form with the help of eqn. 3 we easily arrive at eqn. 10.

Derivation of the main integrals:

The result in eqn. 6 is established by taking the partial drivative on both sides of eqn. 9 with respect to a. Equation 7& 8 are similar established by taking the partial derivate of eqn. 9 with respect to b & c respectively

Special Cases:

If we put $A_j = B_j = 1$, Modified Multivariable *H*-function reduces to fox's *H*-function (Srivastava, 1982 [9], then eqn. 9 takes the form:

$$\int_0^1 \int_0^{1-x} x^{a-1} y^{b-1} (1 - x - y)^{c-1} \sum_{i=1}^{r} S_{n_i}^{m_i} [c_i x^{u_i} y^{v_i} (1 - x - y)^{w_i}]$$

$$H_{p,q:|R:p_1,q_1;\dots .;\, p_r,q_r}^{m,n:|R':m_1,n_1;,\dots;m_r,n_r} \begin{bmatrix} z_1 x^{u_i} y^{v_i} (1 - x - y)^{w_i} \\ \vdots \\ z_r x^{u_r} y^{v_r} (1 - x - y)^{w_r} \end{bmatrix} dxdy$$

$$= \prod_{i=1}^{r} \sum_{l_i=0}^{[n_i|m_i]} \frac{(-n_i)_{m_i l_i}}{l_i!} \mathrm{A}_{n_i l_i} C_i^{l_i} H_{p+3,q+1:|R:p_1 q_1;\dots\dots;p_r,q_r}^{m_1 n+3:|R':m_1 n_1;\dots\dots;m_r,n_r} \begin{bmatrix} z_1 \\ \vdots \\ z_r \end{bmatrix}$$

$$\left(1 - a - \sum_{i=1}^{r} u_i l_i, u\right), \left(1 - b - \sum_{i=1}^{r} v_i l_i, v\right) \left(1 - c - \sum_{i=1}^{r} w_i l_i, w\right) \left(a_j ; \alpha_j', \dots \alpha_j^{(r)}\right)_{1,p} : \left(e_j ; u_j' g_j', \dots, u_j^{(r)} g_j^{(r)}\right)_{1,|R'} :$$

$$\left(b_j ;\, B_j', \dots, \beta_j^{(r)}\right)_{1,q} ; \left(l_j ;\, U_j' f_j', \dots, U_j^{(r)} F_j^{(r)}\right)_{1,|R} ; \left(\, d_j', \delta_j'\right)_{1,q_1} ; \dots . ; \left(\, d_j^{(r)}, \delta_j^{(r)}\right)_{1,q_r} ;$$

$$\left.\begin{matrix}(c_j',\gamma_j')_{1,p_1},\ldots,\left(c_j^{(r)},c_j^{(r)}\right)_{1,p_r}; \\ (1-a-b-c-\sum_{i=1}^{r}(u_i+v_i+w_i)l_i, u+v+w)\end{matrix}\right] \quad (13)$$

If we put $A_j = B_j = 1, ; \alpha_j = \beta_j = 1$ then the Modified Multivariable *H*-function reduces to general type of *G*-function (Meijer, 1946 [14], which is also believe to be new

The conditions of convergence of eqn. (13) can be easily obtained from the eqn. 9.
By applying our result given in eqn. 9 to the case of Hermite Polynomials (Srivastava and Singh, 1983) [10] by Setting

$$S_{n_l}^{2}(x) \to x^{n_l/2} H_{n_l}\left[\frac{1}{2\sqrt{x}}\right]$$

In which $m_i = 2;\ n_i = n_l; r = 1; A_{n_i,l_i} = (-1)^{l_i},$ we have the following interesting results.

$$\int_0^1\int_0^{1-x} x^{a-1}\, y^{b-1}\,(1-x-y)^{c-1}\,[c_i^{l_i}x^{u_i}y^{v_i}(1-x-y)^{w_i}]^{n/2}\, H_n\left[\frac{1}{2\sqrt{c_i^{l_i}x^{u_i}y^{v_i}(1-x-y)^{w_i}}}\right]$$

$$H_{p,q:|R:p_1,q_1;\ldots;\,p_r,q_r}^{m,n:|R':m_1,n_1;,\ldots;m_r,n_r}\begin{bmatrix} z_1x^{u_i}y^{v_i}(1-x-y)^{w_i} \\ \vdots \\ z_rx^{u_r}y^{v_r}(1-x-y)^{w_r}\end{bmatrix} dxdy$$

$$= \sum_{l_i=0}^{[n_i|m_i]} \frac{(-n_i)_{m_il_i}}{l_i!}\, A_{n_il_i}\, C_i^{l_i} H_{p+3,q+1:|R:p_1q_1;\ldots\ldots;p_r,q_r}^{m_1n+3:|R':m_1n_1;\ldots\ldots;m_r,n_r}\left[\begin{matrix} z_1 \\ \vdots \\ z_r\end{matrix}\right|$$

$$(1-a-u_il_i,u;l),(1-b-v_il_i,v;l)(1-c-w_il_i,w;l)\left(a_j;\alpha_j',\ldots\alpha_j^{(r)}\right)_{1,p}:\left(e_j;u_j'g_j',\ldots,u_j^{(r)}g_j^{(r)}\right)_{1|R'}:$$

$$\left(b_j;\ B_j',\ldots,\beta_j^{(r)}\right)_{1,q};\left(l_j;\ U_j'f_j',\ldots,U_j^{(r)}F_j^{(r)}\right)_{1,|R};\left(d_j',\delta_j'\right)_{1,q_1};\ldots;\left(d_j^{(r)},\delta_j^{(r)}\right)_{1,q_r};$$

$$\left.\begin{matrix}(c_j',\gamma_j')_{1,p_1},\ldots,\left(c_j^{(r)},c_j^{(r)}\right)_{1,p_r}; \\ (1-a-b-c-(u_i+v_i+w_i)l_i, u+v+w;1)\end{matrix}\right] \quad (14)$$

The conditions of convergence of eqn. 14 can be easily obtained from those of eqn. 9.

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