Research Article

On Generalization Based on Bi et al. Iterative Methods with Eighth-Order Convergence for Solving Nonlinear Equations

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The primary goal of this work is to provide a general optimal three-step class of iterative methods without memory, which employs the idea of weight functions in the second and third steps. The order of this class is eight requiring four functional evaluations per step and therefore it supports Kung and Traub’s conjecture [8]. The proposed class includes the Bi et al. methods [6, 7].

In order to design the new methods, we will use the divided differences. Let \( f(x) \) be a function defined on an interval \( I \), where \( I \) is the smallest interval containing \( k + 1 \) distinct nodes \( x_0, x_1, \ldots, x_k \). The divided difference \( f[x_0, x_1, \ldots, x_k] \) with \( k \)-th order is defined as follows:

\[
f[x_0, x_1, \ldots, x_k] = \frac{f[x_1, x_2, \ldots, x_k] - f[x_0, x_1, \ldots, x_{k-1}]}{x_k - x_0}.
\]

It is clear that the divided difference \( f[x_0, x_1, \ldots, x_k] \) is a symmetric function of its arguments \( x_0, x_1, \ldots, x_k \). Moreover, if we assume that \( f \in C^{(k+1)}(I_\xi) \), where \( I_\xi \) is the smallest interval containing the nodes \( x_0, x_1, \ldots, x_k \), and \( x \), then

\[
f[x_0, x_1, \ldots, x_k, x] = f^{(k+1)}(\xi)/(k + 1)!
\]

for a suitable \( \xi \in I_\xi \). Specially, if \( x_0 = x_1 = \cdots = x_k = x \), then

\[
f[x, x, \ldots, x, x] = \frac{f^{(k+1)}(x)}{(k + 1)!}.
\]
Moreover, we recall the so-called efficiency index defined by Ostrowski [38] as $EI = p^{1/n}$, where $p$ is the order of convergence and $n$ is the total number of functional evaluations per iteration.

2. Main Result: Development and Convergence

Analysis of the New Methods

It is well known that Newton’s method converges quadratically under standard conditions. To obtain a higher order of convergence and higher efficiency index than that of Newton’s scheme, we compose Newton’s method twice as follows:

\[ y_n = x_n - \frac{f(x_n)}{f'(x_n)}, \quad z_n = y_n - \frac{f'(y_n)}{f''(y_n)}, \]

\[ x_{n+1} = z_n - \frac{f(z_n)}{f'(z_n)}, \quad n = 0, 1, 2, \ldots. \]  

(3)

As this scheme is eighth-order convergent but its efficiency is poor, we need to reduce the number of functional evaluations. In the third step, $f'(z_n)$ can be approximated in a similar way as in [6].

Consider

\[ f'(z_n) \approx f[z_n, y_n] + f[z_n, x_n, x_n](z_n - y_n). \]  

(4)

Also, a “frozen” derivative can be used in the second step and adequate weight functions will improve the efficiency in the second and last steps. So, the following three-step methods are proposed:

\[ y_n = x_n - \frac{f(x_n)}{f'(x_n)}, \quad z_n = y_n - g(s_n) \frac{f'(y_n)}{f''(x_n)}, \]

\[ s_n = \frac{f(y_n)}{f(x_n)}, \]

\[ x_{n+1} = z_n - h(t_n) \frac{f(z_n)}{f[z_n, y_n] + f[z_n, x_n, x_n](z_n - y_n)} \]

\[ t_n = \frac{f(z_n)}{f(x_n)} \]  

(5)

It is clear that the proposed methods by (5) require only four functional evaluations per iteration, while they are not eighth-order methods, in general. To recover the optimal eighth-order, we find some suitable conditions on the introduced weight functions $g(s_n)$ and $h(t_n)$.

To find the weight functions $g$ and $h$ in (5) providing order eight, we will use the method of undetermined coefficients and Taylor’s series about 0, since $t_n \to 0$, $s_n \to 0$, when $n \to \infty$.

Let us consider

\[ g(s_n) = g(0) + g'(0) s_n + g''(0) \frac{s_n^2}{2}, \]

\[ h(t_n) = h(0) + h'(0) t_n. \]  

(6)

The following result states suitable conditions for proving that the new class has eighth-order of convergence.

Theorem 1. Assume that $f$ is a sufficiently differentiable real function. Let one suppose that $\alpha \in D$ is a simple zero of $f$. If the initial estimation $x_0$ is close enough to $\alpha$, then the sequence $\{x_n\}$ generated by any method of the family (5) converges with eighth-order of convergence if $g$ and $h$ are real sufficiently differentiable functions satisfying $g(0) = h(0) = 1$, $g'(0) = h'(0) = 2$, and $g''(0) = 10$.

Proof. Let us introduce the following notations:

\[ e_n = x_n - \alpha, \quad e_{y_n} = y_n - \alpha, \quad e_{z_n} = z_n - \alpha, \]

\[ e_{n+1} = x_{n+1} - \alpha, \quad c_i = \frac{1}{i!} f^{(i)}(\alpha), \quad i \geq 2. \]  

(7)

Using Taylor’s expansion and taking into account $f(\alpha) = 0$, we have

\[ f(x_n) = f'(\alpha) \left[ e_n + c_2 e_n^2 + c_3 e_n^3 + c_4 e_n^4 \right. \]

\[ + c_5 e_n^5 + c_6 e_n^6 + c_7 e_n^7 + c_8 e_n^8 \]  

+ $O(e_n^9).$  

(8)

Also by direct differentiation, we obtain

\[ f'(x_n) = f'(\alpha) \left[ 1 + 2c_2 e_n + 3c_3 e_n^2 + 4c_4 e_n^3 + 5c_5 e_n^4 \right. \]

\[ + 6c_6 e_n^5 + 7c_7 e_n^6 + 8c_8 e_n^7 \]  

+ $O(e_n^8).$  

(9)

From (8) and (9) we get

\[ f(x_n) \]

\[ \frac{f'(x_n)}{f'(x_n)} \]

\[ = e_n - c_2 e_n^2 + 2 \left( c_2^2 - c_2 \right) e_n^3 + \left( 7c_2 c_3 - 4c_2^3 - 3c_4 \right) e_n^4 \]

\[ + \left( 8c_2^4 - 20c_2^2 c_4 + 6c_2^3 + 10c_2 c_4 - 4c_4 \right) e_n^5 \]

\[ + \left[ -16c_2^5 + 52c_2^3 c_3 - 28c_2^2 c_4 + 17c_2 c_5 \right. \]

\[ + c_5\left( -33c_2^3 + 13c_2^2 \right) - 5c_6 \]  

\[ \left. + 2 \left[ 16c_2^6 - 64c_2^5 c_3 + 9c_3^2 + 36c_2^3 c_4 + 6c_2^2 + 9c_2 \left( 7c_2^2 - 2c_2 \right) \right. \]

\[ + 11c_2 c_3 + c_2 \left( -46c_3 c_5 + 8c_3 \right) - 3c_4 \right) e_n^6 \]

\[ + \left[ -64c_2^7 + 304c_2^6 c_3 - 176c_2^5 c_4 \right. \]

\[ - 75c_2^5 c_4 + 31c_4 c_5 + c_3 \left( -408c_2^2 + 92c_3 \right) \]

\[ + 4c_2 \left( 87c_2 c_4 - 11c_5 \right) + 27c_5 c_6 \]

\[ + c_2 \left[ 135c_2^3 - 64c_2^2 - 118c_3 c_5 + 19c_3 \right. \]

\[ \left. - 7c_4 \right) \]  

\[ \times e_n^8 + O(e_n^9). \]  

(10)
Hence,

\[ e_{yn} = c_2 e_n^2 + 2 \left( -c_2^2 + c_3 \right) e_n^3 + \left( -7c_2 c_3 + 4c_4 + 3c_5 \right) e_n^4 \]
\[ - 8c_2^4 - 20c_2^2 c_4 + 6c_2^2 + 10c_2 c_4 - 4c_5 \right) e_n^5 \]
\[ - \left[ -16c_2^5 + 52c_2^3 c_3 - 28c_2^3 c_4 \right. \]
\[ + 17c_2 c_4 + c_2 \left( -33c_3^2 + 13c_5 \right) - 5c_6 \right] e_n^6 \]
\[ - 2 \left[ 16c_2^6 - 64c_2^4 c_3 - 9c_2^4 + 36c_2^4 c_4 + 6c_2^6 \right. \]
\[ + 9c_2^2 \left( 7c_2^2 - 2c_3 + 11c_3 c_5 \right) \]
\[ + c_2 \left( -46c_2 c_4 + 8c_6 - 3c_7 \right] e_n^7 \]
\[ - \left[ -64c_2^7 + 304c_2^5 c_3 - 176c_2^5 c_4 \right. \]
\[ - 75c_2^5 c_4 + 31c_2^4 c_5 + c_2^3 \left( -408c_2^3 + 92c_5 \right) \]
\[ + 4c_2^3 \left( 87c_2 c_4 - 11c_5 \right) + 27c_5 c_6 \]
\[ + c_2 \left( 135c_3^3 - 64c_2^3 - 118c_2 c_5 + 19c_5 \right) - 7c_8 \]
\[ \times e_n^8 + O \left( e_n^9 \right). \] (11)

Similar to (8),

\[
\frac{f(y_n)}{f'(x_n)} = c_2 e_n^2 + \left( -4c_2^2 + 2c_3 \right) e_n^3 \]
\[ + \left( 13c_2^3 - 14c_2 c_3 + 3c_4 \right) e_n^4 \]
\[ + \left( -38c_2^4 + 64c_2^2 c_3 - 20c_2 c_4 + 4 \left( -3c_2^2 + c_5 \right) \right) e_n^5 \]
\[ \times e_n^6 + O \left( e_n^7 \right). \] (14)

By using Taylor’s expansion around zero

\[
g (s_n) = g (0) + g' (0) s_n + \frac{g'' (0)}{2} s_n^2, \] (15)

and by using (11)–(15),

\[
e_{yn} = A_2 e_n^2 + A_3 e_n^3 + A_4 e_n^4 + O \left( e_n^5 \right), \] (16)

where \( A_2 = (1 - g(0)) c_2, \) \( A_3 = \left( -2 + 4g(0) - g'(0) \right) c_2^2 - 2(1 + g(0)) c_3, \) and

\[
A_4 = \left( 4 - 13g(0) + 7g'(0) - \frac{g''(0)}{2} \right) c_2^3 \]
\[ + \left( -7 + 14g(0) - 4g'(0) \right) c_2 c_3 - 3 \left( -1 + g(0) \right) c_4 \right). \] (17)

We now need to vanish \( A_3 \) and \( A_4 \) not only for making the first two steps optimal but also for simplifying subsequent relations. It is enough to ask the weight function \( g \) to satisfy conditions \( g(0) = 1 \) and \( g'(0) = 2. \) Then

\[
e_{yn} = \left( 5 - \frac{g''(0)}{2} \right) c_2^3 - c_2 c_3 \right) e_n^4 + O \left( e_n^5 \right). \] (18)

For the third step, we also require

\[
t_n = \frac{f(z_n)}{f'(x_n)} \]
\[ = \left( 5 - \frac{g''(0)}{2} \right) c_2^3 - c_2 c_3 \right) e_n^4 \]
\[ + \left( -41 + \frac{11g''(0)}{2} \right) c_2^4 \]
\[ - 3 \left( -11 + g''(0) \right) c_2 c_3 - 2c_2 c_4 \right) e_n^4 \]
+ \left[ \frac{3}{2} (-200 + 27g''(0)) c_2^2 c_3 \right] e_n^5
+ \left[ \frac{1}{2} \left( 100 - 9g''(0) \right) c_2^2 c_4 - 7c_3 c_4 \right] e_n^5 + O(e_n^6),

(19)

f [z_n, y_n] = f'(\alpha) \left[ 1 + c_2^2 e_n^2 + 2c_2 \left(-c_2^2 + c_3 \right) e_n^2 \right.
- \frac{1}{2} c_2 \left( -18 + g''(0) \right) c_2^2 + 14c_2 c_3 - 6c_4 \left] e_n^4 \right. + O(e_n^5),

(20)

f [z_n, x_n, x_n]
= f'(\alpha) \left[ c_2 + 2c_3 e_n + 3c_4 e_n^2 \right.
- \frac{1}{2} \left( c_2 c_3 \left(-10 + g''(0) \right) c_2^2 + 2c_3 \right) e_n^3 \left] e_n^3 \right. + O(e_n^4),

(21)

Now let

h(t_n) = h(0) + h'(0) t_n.

(22)

Taking into account relations (19)–(22) and the third step of (5), we get

\begin{align*}
\epsilon_{n+1} &= \epsilon_{z_n} - h(t_n) \frac{f(z_n)}{f[z_n, y_n] + f[z_n, x_n, x_n]} (\epsilon_{z_n} - e_{y_n}) \\
&= B_4 e_n^4 + B_5 e_n^5 + B_6 e_n^6 + B_7 e_n^7 + B_8 e_n^8 + O(e_n^9),
\end{align*}

(23)

where

\begin{align*}
B_4 &= \frac{1}{2} (-1 + h(0)) c_3 ((-10 + g''(0)) c_2^2 + 2c_3), \quad \text{and}
B_5 &= B_6 = B_7 = B_8 = 0 \text{ at once that } B_4 = B_5 = B_6 = 0.
\end{align*}

(24)

Finally, taking $g''(0) = 10$ and $h'(0) = 2$, we obtain

\begin{align*}
\epsilon_{n+1} &= c_2^2 c_3 \left( 28c_3^2 + 2c_2 c_3 - c_4 \right) e_n^8 + O(e_n^9),
\end{align*}

(25)

which shows that under the provided conditions on weight functions $g$ and $h$ the method (5) has eighth-order convergence and it is optimal. This finishes the proof.

According to the above analysis, we can obtain the following special cases.

**Corollary 2.** If one sets $g(s_n) = (1 + \beta s_n)/(1 + (\beta - 2) s_n) = (f(x_n) + \beta f(y_n))/(f(x_n) + (\beta - 2) f(y_n))$, scheme (14) in [6] is obtained.

Consider

\begin{align*}
y_n &= x_n - \frac{f(x_n)}{f'(x_n)},
\end{align*}

(26)

\begin{align*}
z_n &= y_n - \frac{f(x_n) + \beta f(y_n)}{f(x_n) + (\beta - 2) f(y_n)}, \quad \beta = -\frac{1}{2},
\end{align*}

\begin{align*}
x_{n+1} &= z_n - h(t_n) \frac{f(z_n)}{f(z_n, y_n) + f(z_n, x_n, x_n)} (z_n - y_n),
\end{align*}

\begin{align*}
t_n &= \frac{f(z_n)}{f(x_n)}.
\end{align*}

Corollary 3. If one sets $h(t_n) = (1 + \theta t_n)/(1 + (\theta - 2) t_n) = (f(x_n) + \theta f(z_n))/(f(x_n) + (\theta - 2) f(z_n))$, $\theta \in R$, our proposed method becomes scheme (13) in [7].

Consider

\begin{align*}
y_n &= x_n - \frac{f(x_n)}{f'(x_n)},
\end{align*}

(27)

\begin{align*}
z_n &= y_n - g(s_n) \frac{f(y_n)}{f'(y_n)}, \quad s_n = \frac{f(y_n)}{f(x_n)}
\end{align*}

\begin{align*}
x_{n+1} &= z_n - \frac{f(x_n) + \theta f(z_n)}{f(x_n) + (\theta - 2) f(z_n)} \frac{f(z_n)}{f(z_n, y_n) + f(z_n, x_n, x_n)} (z_n - y_n),
\end{align*}

In addition to those from Corollaries 2 and 3, some simple but efficient weight functions which satisfy conditions of Theorem 1 are

\begin{align*}
g_1(s_n) &= \frac{2 - s_n}{2 - 5s_n} = \frac{2f(x_n) - f(y_n)}{2f(x_n) - 5f(y_n)},
\end{align*}

\begin{align*}
g_2(s_n) &= \frac{1}{1 - 2s_n - s_n^2} = \frac{f(x_n)^2}{f(x_n)^2 - 2f(x_n)f(y_n) - f(y_n)^2},
\end{align*}

\begin{align*}
g_3(s_n) &= 1 + 2s_n + 5s_n^2 = \frac{f(x_n)^2 + 2f(x_n)f(y_n) + 5f(y_n)^2}{f(x_n)^2}.
\end{align*}
3. Some Concrete Methods

In this section, we put forward some particular three-step methods based on the general class designed in this work.

3.1. Methods 1 and 2. Firstly, by combining the methods (26) and (27),

\[
y_n = x_n - \frac{f(x_n)}{f'(x_n)}, \\
z_n = y_n - \frac{f(x_n) + \beta f(y_n)}{f(x_n) + (\beta - 2) f(y_n)} \frac{f(y_n)}{f'(x_n)}, \quad \beta = -\frac{1}{2}, \\
x_{n+1} = z_n - \frac{f(x_n) + \theta f(z_n)}{f(x_n) + (\theta - 2) f(z_n)} \frac{f(z_n)}{f'(z_n)} \\
\times \frac{f(z_n)}{f[z_n, y_n] + f[z_n, x_n, x_n] (z_n - y_n)}, \quad \theta \in \mathbb{R},
\]

(28)

Consequently, a special case of (29) appears when \( s_1(s_n) = (2 - s_n)/(2 - 5s_n) = (2 f(x_n) - f(y_n))/(2 f(x_n) - 5 f(y_n)) \) and \( h_1(t_n) = 1/(1 - 2t_n) = f(x_n)/(f(x_n) - 2 f(z_n)), \quad (\theta = 0): \)

\[
y_n = x_n - \frac{f(x_n)}{f'(x_n)}, \\
z_n = y_n - \frac{2 f(x_n) - f(y_n)}{2 f(x_n) - 5 f(y_n)} \frac{f(y_n)}{f'(x_n)}, \quad \beta = -\frac{1}{2}, \\
x_{n+1} = z_n - \frac{f(x_n) - 2 f(z_n)}{f(x_n) - 2 f(z_n)} \frac{f(z_n)}{f[z_n, y_n] + f[z_n, x_n, x_n] (z_n - y_n)}.
\]

(30)

3.2. Method 3. Now, let us substitute \( g_1(s_n) = (2 - s_n)/(2 - 5s_n) = (2 f(x_n) - f(y_n))/(2 f(x_n) - 5 f(y_n)) \) and \( h_2(t_n) = 1 + 2 t_n = (f(x_n) + 2 f(z_n))/f(x_n) \) into (5). It gives us the following iterative scheme:

\[
y_n = x_n - \frac{f(x_n)}{f'(x_n)}, \\
z_n = y_n - \frac{2 f(x_n) - f(y_n)}{2 f(x_n) - 5 f(y_n)} \frac{f(y_n)}{f'(x_n)}, \quad \beta = -\frac{1}{2},
\]

3.3. Method 4. Let us consider \( g_2(s_n) = 1/(1 - t_n)^2 = f(x_n)^2/(f(x_n)^2 - 2 f(x_n) f(y_n) - f(y_n)^2) \) and \( h_1(t_n) = 1/(1 - 2t_n) = f(x_n)/(f(x_n) - 2 f(z_n)), \quad (\theta = 0) \). By using them in (5), we have

\[
y_n = x_n - \frac{f(x_n)}{f'(x_n)}, \\
z_n = y_n - \frac{f(x_n)^2}{f(x_n)^2 - 2 f(x_n) f(y_n) - f(y_n)^2} \frac{f(y_n)}{f'(x_n)}, \\
x_{n+1} = z_n - \frac{f(x_n)}{f(x_n) - 2 f(z_n)} \times \frac{f(z_n)}{f[z_n, y_n] + f[z_n, x_n, x_n] (z_n - y_n)}.
\]

(31)

3.4. Method 5. If we consider \( g_3(s_n) = 1/(1 - t_n)^2 = f(x_n)^2/(f(x_n)^2 - 2 f(x_n) f(y_n) - f(y_n)^2) \) and \( h_2(t_n) = 1 + 2 t_n = (f(x_n) + 2 f(z_n))/f(x_n) \) in (5), we have

\[
y_n = x_n - \frac{f(x_n)}{f'(x_n)}, \\
z_n = y_n - \frac{f(x_n)^2}{f(x_n)^2 - 2 f(x_n) f(y_n) - f(y_n)^2} \frac{f(y_n)}{f'(x_n)}, \\
x_{n+1} = z_n - \frac{f(x_n) + 2 f(z_n)}{f(x_n)} \times \frac{f(z_n)}{f[z_n, y_n] + f[z_n, x_n, x_n] (z_n - y_n)}.
\]

(32)

3.5. Method 6. When \( g_4(s_n) = 1 + 2 s_n + 5 s_n^2 = (f(x_n)^2 + 2 f(x_n) f(y_n) + 5 f(y_n)^2)/f(x_n)^2 \) and \( h_1(t_n) = 1/(1 - 2t_n) = f(x_n)/(f(x_n) - 2 f(z_n)), \quad (\theta = 0) \) in (5), we get

\[
y_n = x_n - \frac{f(x_n)}{f'(x_n)}, \\
z_n = y_n - \frac{f(x_n)^2 + 2 f(x_n) f(y_n) + 5 f(y_n)^2}{f(x_n)^2} \frac{f(y_n)}{f'(x_n)}, \\
x_{n+1} = z_n - \frac{f(x_n)}{f(x_n) - 2 f(z_n)} \times \frac{f(z_n)}{f[z_n, y_n] + f[z_n, x_n, x_n] (z_n - y_n)}.
\]

(34)
3.6. Method 7. Finally, if we consider \( g_3(s_n) = 1 + 2s_n + 5s_n^2 \), whose iterative expression is
\[
y_n = y_n - \frac{f(x_n)}{f'(x_n)}, \\
z_n = y_n - \frac{f(x_n)}{f'(x_n)} + \frac{f(y_n)}{f'(x_n)}, \\
x_{n+1} = x_n - \frac{f(z_n)}{f'(x_n)}. \\
\]

3.7. Method 8. This section concerns numerical results of the proposed methods (30)–(35). Moreover, they are compared with Kung-Traub’s method presented in [8], whose iterative expression is
\[
y_n = x_n - \frac{f(x_n)}{f'(x_n)}, \\
z_n = y_n - \frac{f(x_n)}{f'(x_n)} + \frac{f(y_n)}{f'(x_n)}, \\
x_{n+1} = x_n - \frac{f(z_n)}{f'(x_n)}. \\
\]

All the methods (29)–(35) require three functional evaluations, namely, \( f(x_n), f(y_n), \) and \( f(z_n) \), and one of the first derivative, namely, \( f'(x_n) \), per iteration. Therefore, they are optimal in the sense of Kung and Traub’s conjecture for \( n = 4 \) with \( p = 2^3 \). Thus, if we assume that all the evaluations have the same cost, then \( EI = 1.682 \).

4. Numerical Implementation and Comparisons

This section concerns numerical results of the proposed methods (30)–(35). Moreover, they are compared with Kung-Traub’s method presented in [8], whose iterative expression is
\[
y_n = x_n - \frac{f(x_n)}{f'(x_n)}, \\
z_n = y_n - \frac{f(x_n)}{f'(x_n)} + \frac{f(y_n)}{f'(x_n)}, \\
x_{n+1} = x_n - \frac{f(z_n)}{f'(x_n)}. \\
\]

Numerical results have been carried out using Mathematica 8 with 400 digits of precision. In each table, ACOC stands for Approximated Computational Order of Convergence (see [39]), which is given by
\[
p = ACOC = \frac{\ln(|x_{n+1} - x_n|/|x_n - x_{n-1}|^{-1})}{\ln(|x_n - x_{n-1}|/|x_{n-1} - x_{n-2}|^{-1})}. \\
\]

Among many test problems, the following four examples are considered:
\[
f_1(x) = (x - 2) \left( x^6 + x^3 + 1 \right) e^{-x^2}, \quad \alpha = 2, \quad x_0 = 1.8, \\
f_2(x) = x^2 - (1 - x)^{25}, \quad \alpha = 0.1437392 \ldots, \quad x_0 = 2.5, \\
f_3(x) = \prod_{k=1}^{12} (x - k), \quad \alpha = 5, \quad x_0 = 5.3, \\
f_4(x) = e^x \sin(5x) - 2, \quad \alpha = 1.3639 \ldots, \quad x_0 = 1.2. \\
\]

From Table 1, it can be seen that all methods work perfectly. Furthermore, we can see that results from methods (34) and (35) are specially good. Table 2 shows that numerical results are in accordance with their theory well enough. In this example, methods (34) and (35) do not have as good behavior as in Example 1. Table 3 represents an important case. Although methods (34) and (35) are working very well in Example 1, however, they do not produce convergent iterations here. It should be remarked that these divergent sequences show that some methods work better in some cases, while they may not do it in other ones.

Table 4 shows that all the methods work in concordance with theoretical results.

5. Conclusion

A new optimal class of three-step methods without memory has been obtained by generalizing Bi et al. families. This class uses four functional evaluations per iteration and it is optimal in the sense of Kung and Traub’s conjecture. Some elements of the family have been presented and they have been tested in order to show its applicability and efficiency, showing that
these methods work properly and confirm their theoretical aspects.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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