

Δ TOA

()

()

Design a Systolic Processor for Fast and Accurate Radar Identification by Using Δ TOA

A. Naseri Technical Faculty, Imam Hossin University
M. Naderi and H. Shahriar Shahhoseini Faculty of Electrical Engineering,
Iran University of Science and Technology

Abstract

Radar identification algorithms according to time of arrival (TOA), of the pulse train have very good accuracy. Since this accuracy is achieved by hard consequent computation, they are not suitable for real time applications. In this paper a systolic processor has been designed for radar identification using difference time of arrival matrix, Δ TOA. High performance radar identification can be achieved by increasing the size of Δ TOA, which increase the size of systolic array. Increasing the size of systolic array causes the clock propagation delay and asynchronous operation of cells. To overcome the above problems, the Δ TOA matrix has been partitioned. Then the algorithm is applied to the Δ TOA sub matrixes. The simulation results show, the effectiveness of the algorithm when accurate and high-speed identification is needed.

Key words: Radar identification, Matrix computation, Parallel processing, Systolic array.

[]

Hough

(ΔTOA)

:[]

$$\Delta TOA = \begin{pmatrix} 0 & t_2 - t_1 & t_3 - t_1 & \dots & t_{N-1} - t_1 & t_N - t_1 \\ t_2 - t_1 & 0 & t_3 - t_2 & \dots & t_{N-1} - t_2 & t_N - t_2 \\ \vdots & \vdots & \vdots & \dots & \vdots & \vdots \\ t_{N-1} - t_1 & t_{N-1} - t_2 & t_{N-1} - t_3 & \dots & 0 & t_N - t_{N-1} \\ t_N - t_1 & t_N - t_2 & t_N - t_3 & \dots & t_N - t_{N-1} & 0 \end{pmatrix} \quad ()$$

.[-]

.[]

)

$$\Delta TOA(i, j) = |TOA(i) - TOA(j)| \quad 1 \leq i, j \leq N \quad ()$$

(

(ΔTOA^{-1})

ΔTOA^{-1}

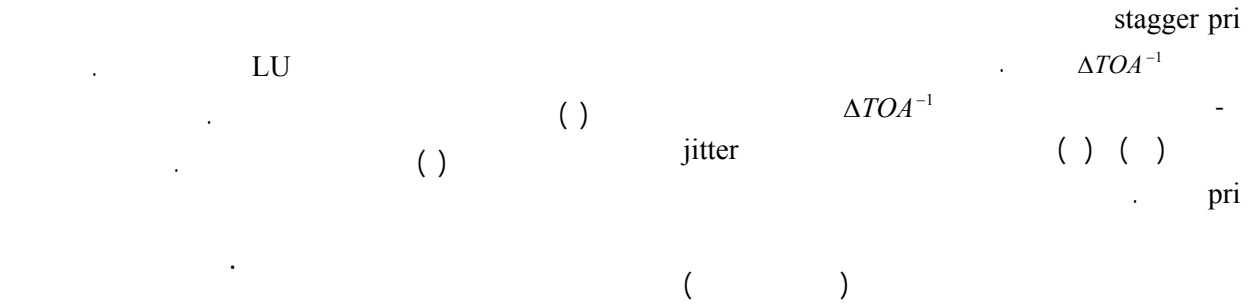
ΔTOA^{-1}

:

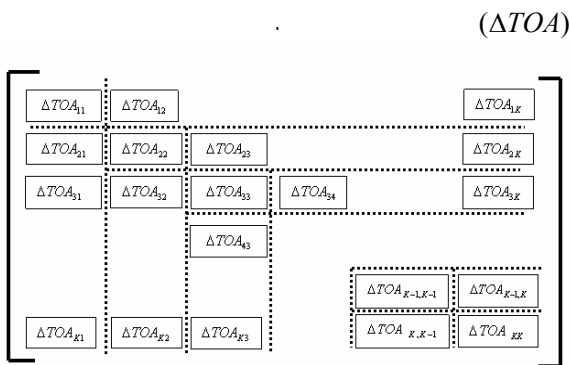
ΔTOA^{-1}

constant pri

ΔTOA^{-1}



$$K^2 \begin{pmatrix} N & N \\ \frac{N}{K} & \frac{N}{K} \end{pmatrix}$$



$$U \quad L \quad ()$$

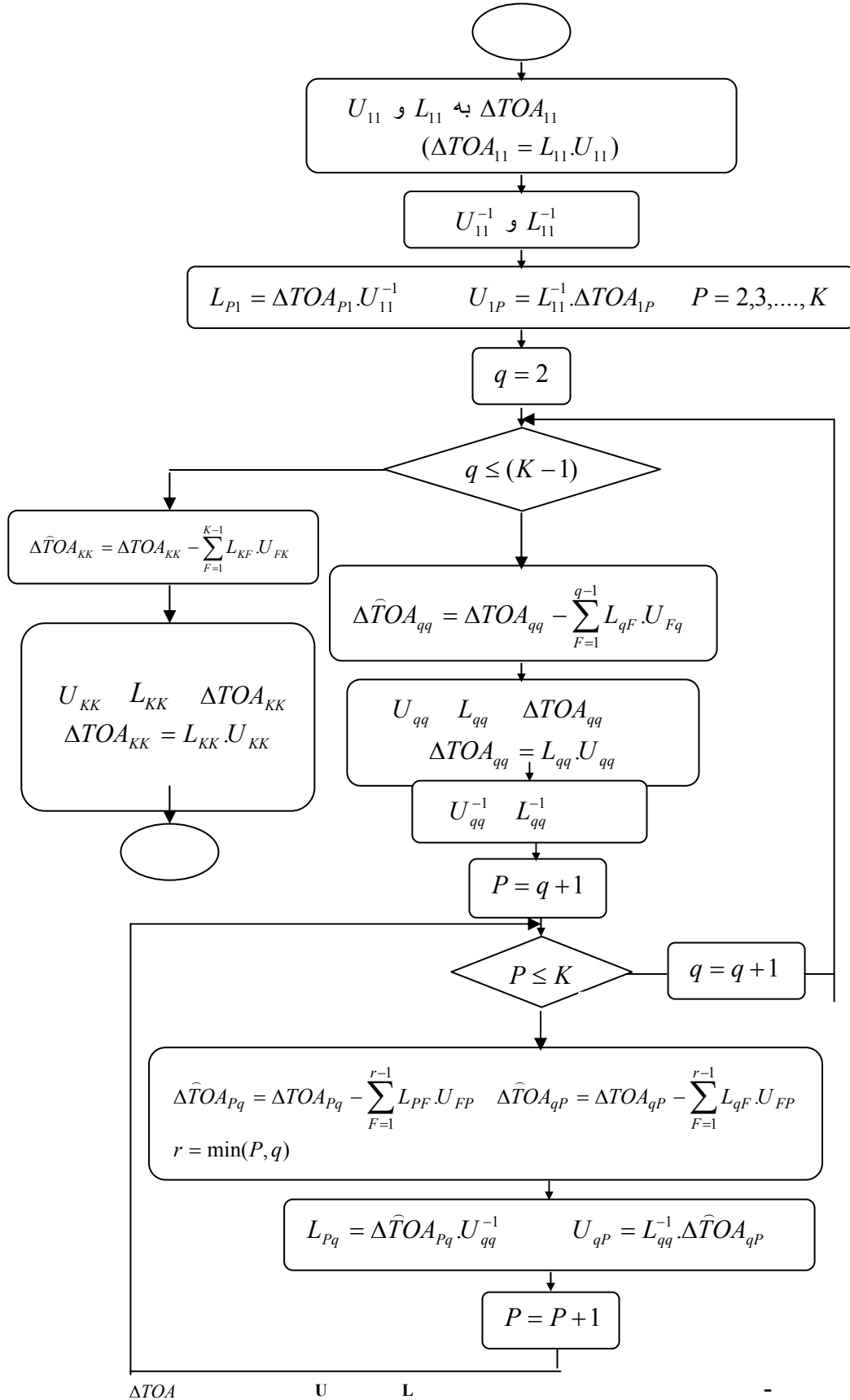
$$U \quad L \quad [U_{ij}] \quad [L_{ij}]$$

VLSI

$$L = \begin{bmatrix} [L_{11}] & [0] & \dots & [0] \\ [L_{21}] & [L_{22}] & \dots & [0] \\ \vdots & \vdots & \ddots & \vdots \\ [L_{K1}] & [L_{K2}] & \dots & [L_{KK}] \end{bmatrix}$$

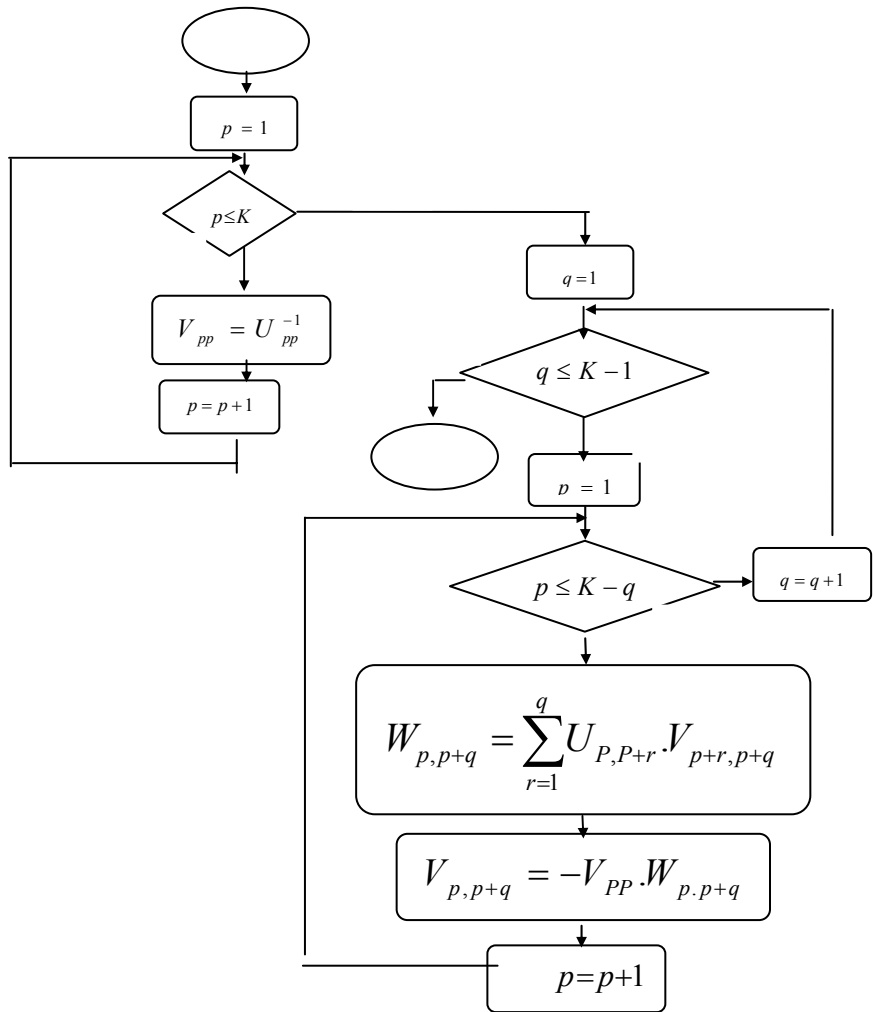
$$U = \begin{bmatrix} [U_{11}] & [U_{12}] & \dots & [U_{1K}] \\ [0] & [U_{22}] & \dots & [U_{2K}] \\ \vdots & \vdots & \ddots & \vdots \\ [0] & [0] & \dots & [U_{KK}] \end{bmatrix}$$

ΔTOA



(U v) v
 U ()
) L)
 () (W
 () ()
 (MMU) [W_{ij}] [V_{ij}]
 (MIU) (LUU) (W v
 W V
 (ΔTOA⁻¹)
 × ()

VLSI



U (U v) v

() . (N

U L

×

K=3

()

×

() () .

)

U

ΔTOA

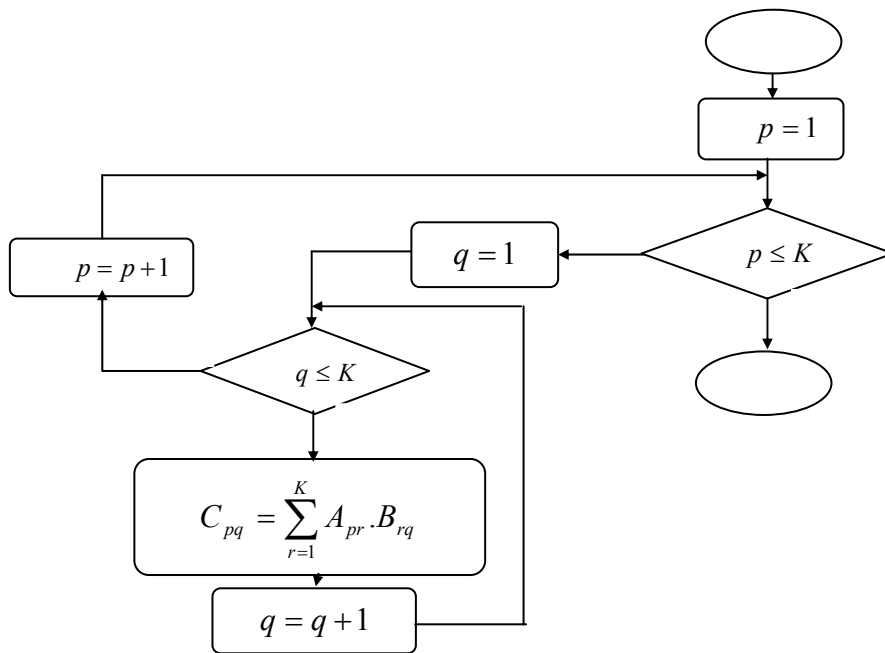
×

()

()

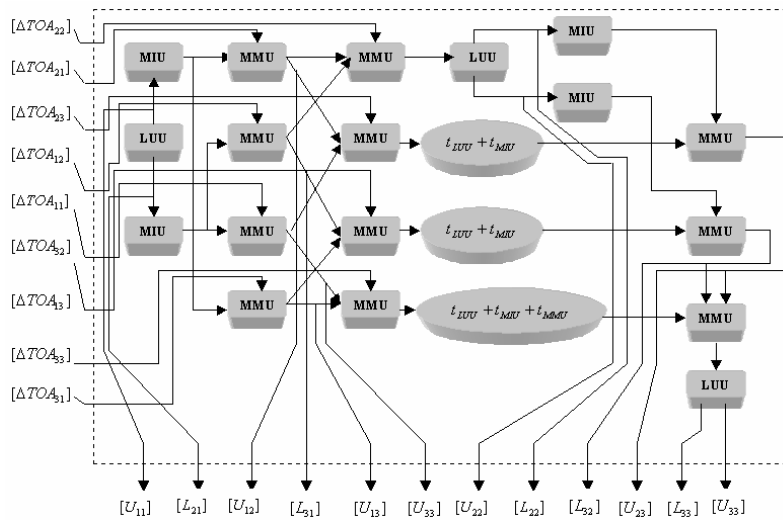
L

K=3

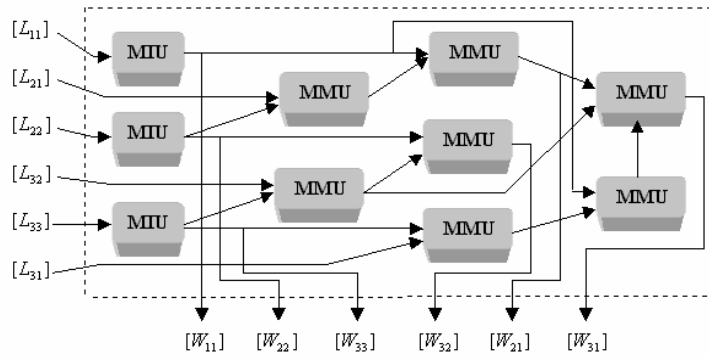


W V

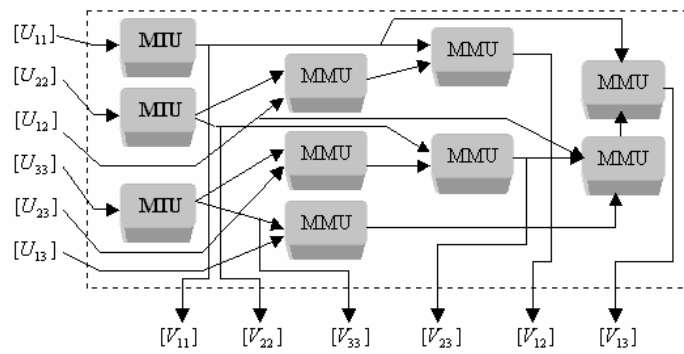
$$\Delta TOA^{-1} = C_{OUT}$$



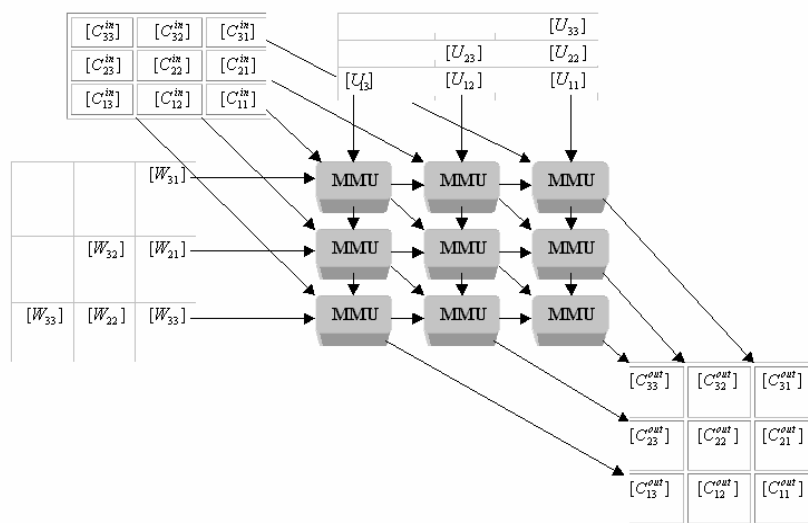
L U



W



V



ΔTOA^{-1}

$$P^t d = 0 \quad S^t b > 0 \quad S^t d > 0$$

()
 () (MMU)
 () (LUU)
 (MIU)
 N×N
 (-)
 AT (T) (A) (Mapping) (DG) (SFG)
 (-) AT^2
 MMU
 (N) (MIU LUU)
 (Pipeline Interval)
 (External I/O)
 ()
 (1,0,0) (0,1,0)
 (0,0,1) MMU
 LUU (1,0,0) (0,1,0)
 (1,0,0) (0,1,0)
 MIU
 MIU LUU MMU
 (-)
 MMU (1,1,0)
 LUU (1,1,0)
 MIU (0,1,0)
 (N)

| | |
|----------------|---|
| DG | |
| Node Mapping | $[C] = P^t [n]$ |
| Arc Mapping | $\begin{bmatrix} D(e) \\ e \end{bmatrix} = \begin{bmatrix} S^t \\ P^t \end{bmatrix} [b]$ |
| Input Mapping | $\begin{bmatrix} T(c) \\ c \end{bmatrix} = \begin{bmatrix} S^t \\ P^t \end{bmatrix} [n]$ |
| Output Mapping | $\begin{bmatrix} T(c) \\ c \end{bmatrix} = \begin{bmatrix} S^t \\ P^t \end{bmatrix} [n] + \begin{bmatrix} 1 \\ 0 \end{bmatrix}$ |

e D(e) SFG C ()
 b S T(c)
 P^t
 S Projection d Projection

(N*N) × (-)

| (Effectiveness) | (Speedup) | (External I/O) | (Pipeline interval) | (Project) |
|---------------------------------|--------------------|----------------|---------------------|-----------|
| $\frac{N}{3N-2}$ | $\frac{N^3}{3N-2}$ | 2N | 1 | (0,0,1) |
| $\frac{N}{3N-2}$ | $\frac{N^3}{3N-2}$ | 3N | 1 | (0,1,0) |
| $\frac{N}{3N-2}$ | $\frac{N^3}{3N-2}$ | 3N | 1 | (1,0,0) |
| $\frac{N^3}{(3N-2)(2N^2-N)}$ | $\frac{N^3}{3N-2}$ | 6N-2 | 2 | (1,1,0) |
| $\frac{N^3}{(3N-2)(2N^2-N)}$ | $\frac{N^3}{3N-2}$ | 5N-1 | 2 | (0,1,-1) |
| $\frac{N^3}{(3N-2)(2N^2-N)}$ | $\frac{N^3}{3N-2}$ | 5N-1 | 2 | (-1,0,1) |
| $\frac{N^3}{(3N-2)(3N^2-3N+1)}$ | $\frac{N^3}{3N-2}$ | 8N-4 | 1 | (1,1,1) |
| $\frac{N^3}{(3N-2)(3N^2-3N+1)}$ | $\frac{N^3}{3N-2}$ | 8N-4 | 1 | (1,-1,1) |
| $\frac{N^3}{(3N-2)(3N^2-3N+1)}$ | $\frac{N^3}{3N-2}$ | 8N-4 | 1 | (-1,1,1) |
| $\frac{N^3}{(3N-2)(3N^2-3N+1)}$ | $\frac{N^3}{3N-2}$ | 8N-4 | 3 | (1,1,-1) |

(N*N) U L

| (Effectiveness) | (Speedup) | (External I/O) | (Pipeline interval) | | | |
|----------------------------------|--------------------|----------------|---------------------|------|-----------------|----------|
| $\frac{11N}{3N^3-2N^2}$ | $\frac{11N}{3N-2}$ | 2N-1 | 1 | N | N^2-N | (0,0,1) |
| $\frac{11N}{1.5N^3+0.5N^2-N}$ | $\frac{11N}{3N-2}$ | 2N-1 | 1 | 1 | $0.5N^2+0.5N-1$ | (0,1,0) |
| $\frac{11N}{3N^3-2N^2}$ | $\frac{11N}{3N-2}$ | 3N-1 | 2 | N | N^2-N | (0,1,1) |
| $\frac{11N}{1.5N^3+0.5N^2-N}$ | $\frac{11N}{3N-2}$ | 2N | 1 | N | $0.5N^2-0.5N$ | (1,0,0) |
| $\frac{11N}{3N^3-2N^2}$ | $\frac{11N}{3N-2}$ | 3N-1 | 2 | N | N^2-N | (1,0,1) |
| $\frac{11N}{3N^3-2N^2}$ | $\frac{11N}{3N-2}$ | 4N-2 | 2 | N | N^2-N | (1,1,0) |
| $\frac{11N}{3N^3-2N^2}$ | $\frac{11N}{3N-2}$ | 4N-2 | 3 | N | N^2-N | (1,1,1) |
| $\frac{11N}{4.5N^3-4.5N^2+N}$ | $\frac{11N}{3N-2}$ | 5N-4 | 1 | N+1 | $1.5N^2-1.5N-1$ | (1,-1,1) |
| $\frac{11N}{4.5N^3-7.5N^2+6N-2}$ | $\frac{11N}{3N-2}$ | 5N-3 | 1 | 2N-1 | $1.5N^2-3.5N+2$ | (-1,1,1) |
| $\frac{11N}{6N^3-10N^2+7N-2}$ | $\frac{11N}{3N-2}$ | 6N-5 | 1 | 2N-1 | $2N^2-4N+2$ | (1,1,-1) |

T_{AP} -

T_{LUD}

ΔTOA

$T_{U^{-1}} \quad T_{L^{-1}} \quad U \quad L$ Jittered PRI staggered PRI constant PRI

U L

$T_{L^{-1} \times U^{-1}} \quad (v \quad w \quad)$

L U

t_{MMU}

$t_{MU} \quad N \quad ()$

$t_{LUU} \quad N$

K N N () $2N^2$ $N^3 + 2N^2$

N^3 ΔTOA

(ΔTOA)

(N×N)

| (Effectiveness) | (Speedup) | (External I/O) | (Pipeline interval) | | | |
|--|---------------------------|----------------|---------------------|------|-----------------|----------|
| $\frac{N^3 + 2N}{15N^3 - 6N^2}$ | $\frac{N^3 + 2N}{5N - 2}$ | 0 | 1 | 4N-2 | $3N^2 - 4N + 2$ | (0,0,1) |
| $\frac{N^3 + 2N}{5N^3 + 3N^2 - 2N}$ | $\frac{N^3 + 2N}{5N - 2}$ | 2N | 1 | 0 | $N^2 + N$ | (0,1,0) |
| $\frac{N^3 + 2N}{10N^3 + 6N^2 - 9N + 2}$ | $\frac{N^3 + 2N}{5N - 2}$ | 2N | 2 | 3N-1 | $2N^2 - N$ | (0,1,1) |
| $\frac{N^3 + 2N}{5N^3 + 3N^2 - 2N}$ | $\frac{N^3 + 2N}{5N - 2}$ | 2N | 1 | N | N^2 | (1,0,0) |
| $\frac{N^3 + 2N}{10N^3 + 6N^2 - 9N + 2}$ | $\frac{N^3 + 2N}{5N - 2}$ | 2N | 2 | 2N | $2N^2 - 1$ | (1,0,1) |
| $\frac{N^3 + 2N}{10N^3 - 4N^2}$ | $\frac{N^3 + 2N}{5N - 2}$ | 4N-2 | 2 | 2N | $2N^2 - 2N$ | (1,1,0) |
| $\frac{N^3 + 2N}{5N^3 + 8N^2 - 4N}$ | $\frac{N^3 + 2N}{5N - 2}$ | 4N-2 | 3 | 2N | N^2 | (1,1,1) |
| $\frac{N^3 + 2N}{15N^3 + 4N^2 - 14N + 4}$ | $\frac{N^3 + 2N}{5N - 2}$ | 4N-2 | 1 | 3N-1 | $3N^2 - N - 1$ | (1,-1,1) |
| $\frac{N^3 + 2N}{15N^3 + 4N^2 - 14N + 4}$ | $\frac{N^3 + 2N}{5N - 2}$ | 4N-2 | 1 | 4N-2 | $3N^2 - 2N$ | (-1,1,1) |
| $\frac{N^3 + 2N}{25N^3 - 25N^2 + 11N - 2}$ | $\frac{N^3 + 2N}{5N - 2}$ | 4N-2 | 1 | 6N-4 | $5N^2 - 9N + 5$ | (1,1,-1) |

($N \times N$)

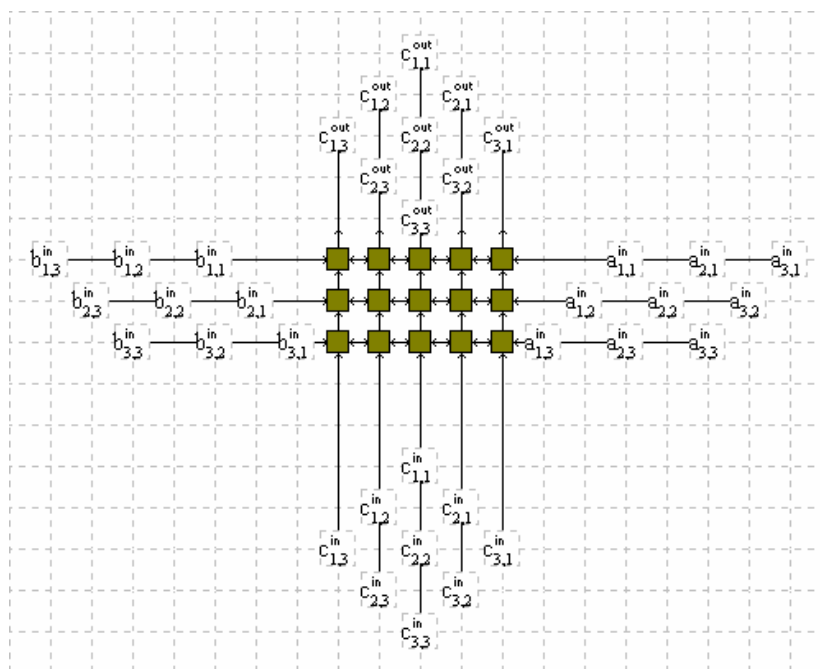
| AT^2 | AT | T | A | |
|-----------------------------------|-------------------------|----------|-----------------|----------|
| $9N^4 - 12N^3 + 4N^2$ | $3N^3 - 2N^2$ | $3N - 2$ | N^2 | (0,0,1) |
| $9N^4 - 12N^3 + 4N^2$ | $3N^3 - 2N^2$ | $3N - 2$ | N^2 | (0,1,0) |
| $9N^4 - 12N^3 + 4N^2$ | $3N^3 - 2N^2$ | $3N - 2$ | N^2 | (1,0,0) |
| $18N^4 - 33N^3 + 20N^2 - 4N$ | $6N^3 - 7N^2 + 2N$ | $3N - 2$ | $2N^2 - N$ | (1,1,0) |
| $18N^4 - 33N^3 + 20N^2 - 4N$ | $6N^3 - 7N^2 + 2N$ | $3N - 2$ | $2N^2 - N$ | (0,1,-1) |
| $18N^4 - 33N^3 + 20N^2 - 4N$ | $6N^3 - 7N^2 + 2N$ | $3N - 2$ | $2N^2 - N$ | (-1,0,1) |
| $27N^4 - 63N^3 + 57N^2 - 24N + 4$ | $9N^3 - 15N^2 + 9N - 2$ | $3N - 2$ | $3N^2 - 3N + 1$ | (1,1,1) |
| $27N^4 - 63N^3 + 57N^2 - 24N + 4$ | $9N^3 - 15N^2 + 9N - 2$ | $3N - 2$ | $3N^2 - 3N + 1$ | (1,-1,1) |
| $27N^4 - 63N^3 + 57N^2 - 24N + 4$ | $9N^3 - 15N^2 + 9N - 2$ | $3N - 2$ | $3N^2 - 3N + 1$ | (-1,1,1) |
| $27N^4 - 63N^3 + 57N^2 - 24N + 4$ | $9N^3 - 15N^2 + 9N - 2$ | $3N - 2$ | $3N^2 - 3N + 1$ | (1,1,-1) |

($N \times N$) U L

| AT^2 | AT | T | A | |
|---------------------------------------|----------------------------|----------|---------------------|----------|
| $9N^4 - 12N^3 + 4N^2$ | $3N^3 - 2N^2$ | $3N - 2$ | N^2 | (0,0,1) |
| $4.5N^4 - 1.5N^3 - 4N^2 + 2N$ | $1.5N^3 + 0.5N^2 - N$ | $3N - 2$ | $0.5N^2 + 0.5N$ | (0,1,0) |
| $9N^4 - 12N^3 + 4N^2$ | $3N^3 - 2N^2$ | $3N - 2$ | N^2 | (0,1,1) |
| $4.5N^4 - 1.5N^3 - 4N^2 + 2N$ | $1.5N^3 + 0.5N^2 - N$ | $3N - 2$ | $0.5N^2 + 0.5N$ | (1,0,0) |
| $9N^4 - 12N^3 + 4N^2$ | $3N^3 - 2N^2$ | $3N - 2$ | N^2 | (1,0,1) |
| $9N^4 - 12N^3 + 4N^2$ | $3N^3 - 2N^2$ | $3N - 2$ | N^2 | (1,1,0) |
| $9N^4 - 12N^3 + 4N^2$ | $3N^3 - 2N^2$ | $3N - 2$ | N^2 | (1,1,1) |
| $13.5N^4 - 22.5N^3 + 12N^2 - 2N$ | $4.5N^3 - 4.5N^2 + N$ | $3N - 2$ | $1.5N^2 - 0.5N$ | (1,-1,1) |
| $13.5N^4 - 31.5N^3 + 33N^2 - 18N + 4$ | $4.5N^3 - 7.5N^2 + 6N - 2$ | $3N - 2$ | $1.5N^2 - 1.5N + 1$ | (-1,1,1) |
| $18N^4 - 42N^3 + 41N^2 - 20N + 4$ | $6N^3 - 10N^2 + 7N - 2$ | $3N - 2$ | $2N^2 - 2N + 1$ | (1,1,-1) |

($N \times N$)

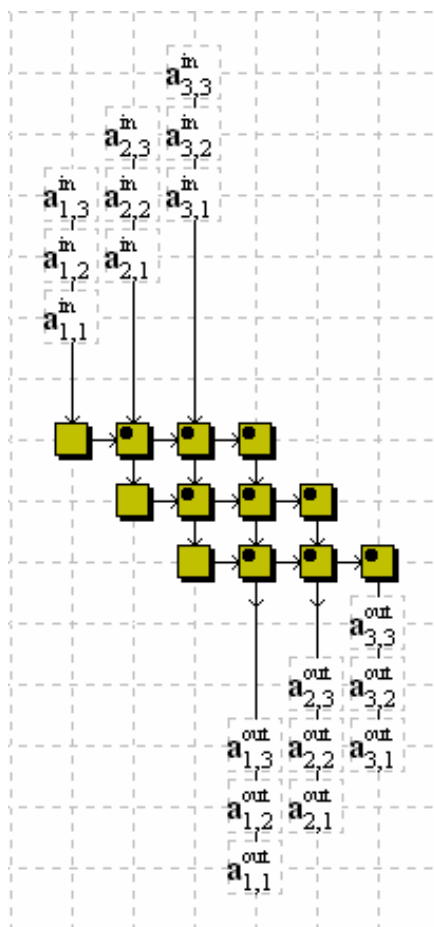
| AT^2 | AT | T | A | |
|--------------------------------------|---------------------------|----------|-----------------|----------|
| $75N^4 - 60N^3 + 12N^2$ | $15N^3 - 6N^2$ | $5N - 2$ | $3N^2$ | (0,0,1) |
| $25N^4 + 5N^3 - 16N^2 + 4N$ | $5N^3 + 3N^2 - 2N$ | $5N - 2$ | $N^2 + N$ | (0,1,0) |
| $50N^4 + 10N^3 - 57N^2 + 28N - 4$ | $10N^3 + 6N^2 - 9N + 2$ | $5N - 2$ | $2N^2 + 2N - 1$ | (0,1,1) |
| $25N^4 + 5N^3 - 16N^2 + 4N$ | $5N^3 + 3N^2 - 2N$ | $5N - 2$ | $N^2 + N$ | (1,0,0) |
| $50N^4 + 10N^3 - 57N^2 + 28N - 4$ | $10N^3 + 6N^2 - 9N + 2$ | $5N - 2$ | $2N^2 + 2N - 1$ | (1,0,1) |
| $25N^4 + 30N^3 - 36N^2 + 8N$ | $5N^3 + 8N^2 - 4N$ | $5N - 2$ | $N^2 + 2N$ | (1,1,1) |
| $75N^4 - 10N^3 - 78N^2 + 48N - 8$ | $15N^3 + 4N^2 - 14N + 4$ | $5N - 2$ | $3N^2 + 2N - 2$ | (1,-1,1) |
| $75N^4 - 10N^3 - 78N^2 + 48N - 8$ | $15N^3 + 4N^2 - 14N + 4$ | $5N - 2$ | $3N^2 + 2N - 2$ | (-1,1,1) |
| $125N^4 - 175N^3 + 105N^2 - 32N + 4$ | $25N^3 - 25N^2 + 11N - 2$ | $5N - 2$ | $5N^2 - 3N + 1$ | (1,1,-1) |



$N = 3$ (1,1,0)

(MMU)

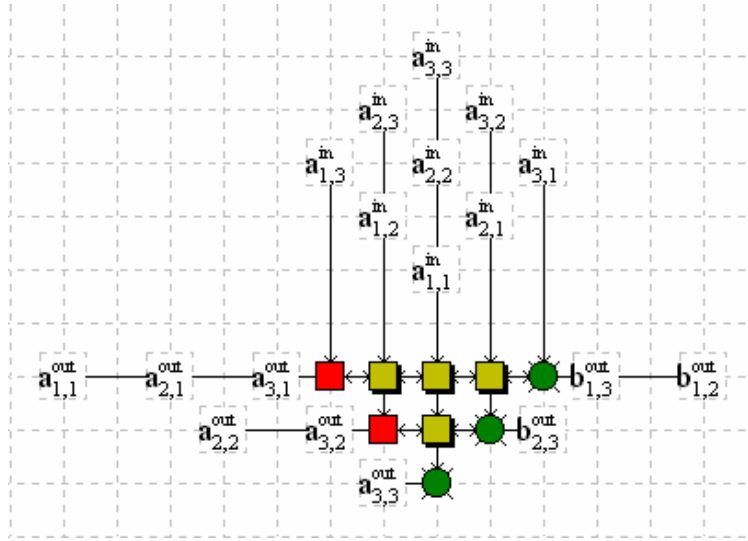
-



$N = 3$ (1,1,0)

(MIU)

-



U L

$N = 3 \quad (1,1,0)$

(LUU)

()

$$T_{AP} = T_{LUD} + T_{L^{-1}} + T_{U^{-1} \times L^{-1}} \quad ()$$

N

$$T_{LUD} = 3t_{LUU} + 2t_{MIU} + 4t_{mmu} \quad ()$$

$$T_{L^{-1}} = t_{MIU} + 4t_{mmu} \quad ()$$

()

$$T_{U^{-1}} = t_{MIU} + 4t_{mmu} \quad ()$$

$$T_{U^{-1} \times L^{-1}} = (3 \frac{N}{K} - 2)t_{MMU} \quad ()$$

$$T_{AP} = (\frac{3N}{K} + 6)t_{MMU} + 3t_{MIU} + 3t_{LUU} \quad ()$$

$$Speedup = \frac{N^3 + 2N^2}{\frac{9}{K}N^2 + (42 - \frac{6}{K})N - 24} \quad ()$$

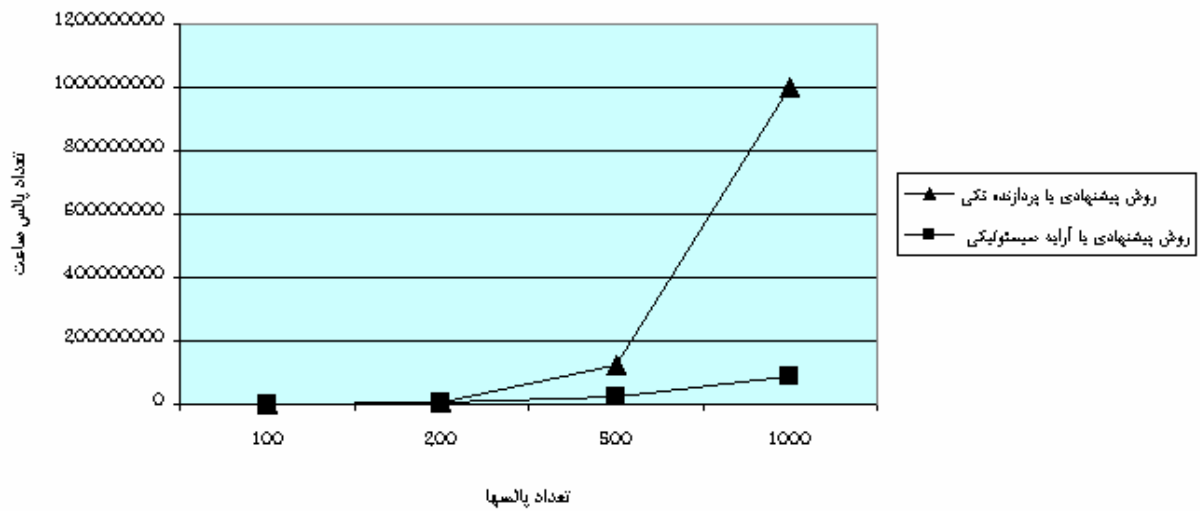
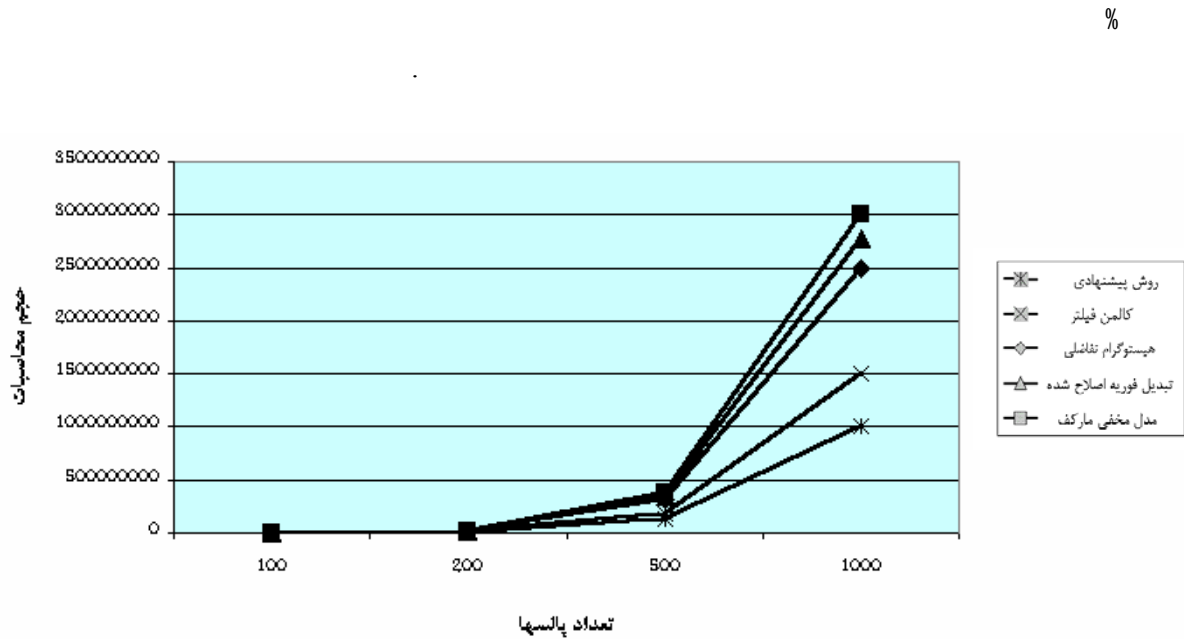
$$t_{LUU} = 3 \frac{N}{K} - 2 \quad t_{MMU} = 3 \frac{N}{K} - 2 \quad t_{MIU} = 5 \frac{N}{K} - 2 \quad ()$$

$$T_{AP} = \frac{9}{K}N^2 + (42 - \frac{6}{K})N - 24 \quad ()$$

) ()

$$T_{AP} = \frac{9}{K}N^2 + (42 - \frac{6}{K})N - 24$$

((% %



Conference, Signal Processing, Pattern Recognition and Application, Greece, pp 98-101, June 2002.

[3] A. Naseri, H. S. Shahhoseini, M. Naderi "Data Clustering by Minimum Difference Tree and PRI Transform", IEEE proceedings, MELECON, pp 183-187, 2002.

[4] Andrew logothetis and Vikram Krishnamurthy, "An interval - Amplitude algorithm for

[1] H. S. Shahhoseini, A. Naseri, M. Naderi, "A New Matrix Method for Pulse Train Identification", IEEE proceedings, MELECON, pp 183-187, 2002.

[2] H.S.Shahhoseini, A. Naseri, M. Naderi, "Matrix Multistage Clustering of Interleaved Pulse Train", IASTED International

- Transactions on aerospace and electronic systems, vol. 34, No. 3, pp. 716-721, July 1998.
- [13] Shek-Wayne Chan and Chin-Long Wey, "The Design of Concurrent Error Diagnosable Systolic Arrays for Band Matrix Multiplications," IEEE Transactions on Computer -Aided Design, vol. 7, No. 1, pp. 21- 37, January 1988 .
- [14] T. Kurtis et. al. "General-Purpose Systolic Arrays," Vol. 26, No. 11, pp. 20-31, November 1993.
- [15] S. Sedukhin and I.Sedukhin "Systematic Approach and Software Tool for Systolic Design." Proc. Intern. Conf. CONPAR'94 - VAPP VI. Sep. 6-8, 1994.
- [16] I.Z. Milovanovic, T. I. Tokic, M . K. Stojcev, E. I. Milovanovic, N. M. NovaKovic, "Mapping Matrix Multiplication Algorithm on to Optimal Fault – Tolerant Systolic Array", MIEL1999, Yugoslavia., PP. 711 –714 , 1999.
- [17] John A. Gunnels and Daniel S.Katz and Enrique S. Quintana –Orti and Robert A. van de Geijn, "Fault – Tolerant High – Performance Matrix Multiplication: Theory and Practice," In Proceedings of the International Conference for Dependable Systems and Networks (DSN-2001), pp. 47 - 55, 2001.
- [18] J. F. Tasic and M. Zajc and A. Kosir, "Comparison of Some Parallel Matrix Multiplication Algorithms", 8th Mediterranean Electrotechnical Conference, MELECON '96., pp. 155 -158, 1996.
- deinterleaving stochastic pulse train sources", IEEE Transactions on signal processing, vol. 46, No. 5, pp.1344-1350, May 1998.
- [5] Robert J. Orsi , Johan B. Moore and Robert E. Mahony, "Interleaved pulse train spectrum estimation", International symposium on signal processing and its applications, ISSPA, gold coast, australia, pp. 125-128, 25-30 August 1996.
- [6] Brian M.Sadler, Stephen D. Casey, "PRI analysis from sparse data via a modified Euclidean algorithm", IEEE proceedings of ASILOMAR – 29, pp. 1147-1151, 1996.
- [7] Jane perkins, Ian coat, "Pulse train deinterleaving via the hough transform", IEEE 1994, International conference on, vol.3, pp. 197- 200, 1994.
- [8] John B. Moore, and Vikram Krishnamurthy, "deinterleaving pulse trains using discrete – time stochastic dynamic linear models.", IEEE, Transaction on signal processing, vol. 42 , No, 11, pp. 3092-3103, November 1994.
- [9] D. J Milojevic, B. M. Popovic, "Improved algorithm for the deinterleaving of radar pulses", IEE proceedings. F, vol. No.1, pp. 98-104, february 1992.
- [10] Mardia H.K., "New techniques for the deinterleaving of repetitive sequences", IEE proceedings, Vol. 136, pt. F, No.4, pp. 149-154, August 1989.
- [11] Mark W. Maier, "Processing throughput estimation for Radar intercept receivers," IEEE Transactions On Aerospace and Electronics Systems, Vol 34, No.1, pp.84-92, Jan 1998.
- [12] P. S. RAY,"A novel pulse TOA analysis technique for radar identification", IEEE