³0 4B # U•2095-4980U‹2023JUŒ2-0208-08

!` 765 Þ$ì u Î"w : = • 0 – 7 E. À$ " 0Ã"

IË 2 U•7û K*U• ™ " U•Sð8º(ÞU• D ª Ã

(Y) /7'•)2-@/¢KŽ *a | /7-@/¢ I U• 4!K_ 621999

„ >- U• T # 0)2 Y ½ b!` • LD¿ Y R '+° : = • 0 – U• [!` 765 Þ$ì u Î"w+° ŸJZ ¬
[w , & º 8 ,!` ,$Eç M Î"w : = • 0+°,$ Ÿ S U• ü & , .ù eE +° ~ , B , ; s å
U‹/ - . 4UŒ7 E. À$ " 0Ã" e š : = • 0+° f Ò ¸$ " :, 3 # S ; Ó b 'J« | U• « ¢ % 9
8C .ç 9 8 f Ò+°, 3 # s6) Ã7› ©+°$ " t È EFDó@Í0Ã f +,K ¸!`!Œ ÊO¸ %0Ã" E =x
O¸@U•3ÿ È=" : U• % 9 8C .ç 9 8 ù 0 f Ò+°, 3 U•A $ " "0Ã" s6) D¯ z+°Kb œ 5 t$ K•
: = • 0 – U• *…, 3 " # :(Ü 5+°7 E. À$ " å" ,$! U• S S û = ²$ " IL,+°@Í0Ã
Bp#½U• T!` 765 Þ$ì u Î"w2'4 6 £ 5 , Æ+° À*T # h
ŸJZ@U•!` 7 Î"w Už: = • 0 Už7 E. À$ " Už~ , B , ; s å0Ã"
Y * 21§ # U•O436UŽN9117 ³(Z 3 -- U•A doiU•10.11805TKYDA 2020461

"O BEBQUJWF GJMUFS BMHPSJUIN PG VOEFSXE CBDLTDBUUFSJOH DPSSFMBUJWF DIE

;) 0 / (, VU0 4 6 8 EU•J1 & / (#UP) 6 " / (4 I B MU•J-O 6H 4 P O H M J O
*OTUJUVUF PG &MFUUSPOJDT &OHJOFFSJOH 4JDIVBO 6OJWFSTJUZ 4JDIVBO 4PVUI 4JDIVBO

"CTUSBDU

CBDLTDBUUFSJOH DPSSFMBUJWF DIBOHFT PG UIF LFZ UFDIOPMPHJFT PG VOEFSXBUFS QVMT
CBDLTDBUUFSFE OPJTF DBVTFE CZ XBU F#SB TUSB OPTON UTF JDPROS SIF MTBUIJDPBOM
UXP BEKBDFOU EFUFDUJPOT PG CBDLBTOD BNQMJGJDBUJPO JOTUBCJMJUJFT JO SUNIBFMT BFNBFTUXB.UFBS
/-.4 BEBQUJWF GJMUFSJOH 5BIMHTPSJUIN CBTFE PO PDTFEUSPMMFE BDDPS
PG CBDLTDBUUFSJOH BOE UIF TJ[F PG UIF GJMUFSFE UBSHFU TJHOB
UBSHFU TJHOBMT BU EJGGFSFOU BEVMUIPPE JOTJEF OVEFSJOJUGFE EFEJCUZJFTTJNVMBU
QPPM FYQFSJFODFT TIPX UIBU UIF GJMUFS BMHPSJUIN DBO FGGFD
XJUI B MPXFS PSEFS GPS UBSHFUT XJUI EJGGFSFOBOUE SSFFGUMBFJDDU UJPIÐ T
UBSHFU FD$PNTQBSBEM XJUI UIF FYJTUJOH JBUE BNQ EBWMZG SMEUFSJSE TO HUINFFDPP
SFTPVSDFT SFRVJSBFOEE GIBST GFNUBSOOBHQ QMJDBUJPO WBMVF JO VOEFS
TZTUFNT

,FZXPUSVEDTE FS XBUFSžŒBFDULFTDUBŽBUEFBSQJUOJHWZFP SNMM F-SF BTU .FBO 4RVBSF

$ì u £ 5 •7ž S f Ú ÒP å = S ©0u'¥%åU•58!` % 0 º: 4+" á+° u d b2' œ , ; U• •: 4+$ì u T
!` 7, 3 Î"w@ò W !` 7 3ëEF 0uM² Ã \ «" À*T [1 7] r!` • : = • 0 2 AB£ 6E 2'4 +° ^ S6) 7Ky U•
f ½ b!` • : = • 0 U• T!` 7 Î"w2'4 Y U•3û dFó*T "K /ÃC .çE5EF å ; [8 11] B/°>ò f å ; [12 13] {:i!` • : = •
0 % Î"wEL <+° • ù r TLŠ 4 ^, 3+° •65 Þ Î"w Y U• 6E 2.ù å ; F R 'D¯ S+°Dý/7, f U• 58 T!` 765 Þ
"wC 2'4 Y U• ùM§ 2A Dý/7, f3ß ' Î"w8/ U• ¢EFDó$ " "´K• : = • 0 % #+° • ù ® È % •65 Þ Î"wE
=x %"´$ " U•*] º j S*aC +° 9-š Æ S U• : = • 0 # 2 ·*…D¯ S+° – U• •, 3 #D¯] " U•*F7 ! , 3
Ì f%ô • U•/7;'0u ý • ² Eƒ |E> Ô , ; ¸ „ (Variable Forgetting Factor Recursive Least SquUare
VFF RLS)7 E. À$ " 0Ã" [14]U•A 0Ã" % : = • 0 #E =x 5 t$ " U• r$ " "Kb œP Dê 400~500KbU•@Í0Ã ,

b/k K U•2020-09-15Už K U•2020-12-24
&FýM¥, U•) â7 &b.ý ' &FýBp ÕM¥, (61505184
*EF ^51 U•7û K emailjohn4546@126com

J,D¯ SUžAY ÆDü ü & ² Ef | , ; s å U‹Variable Forgetting Factor Least Mean Square,VEF LMSUŒZ E. À $ " 0Ã" [15]U• L,>- 8Kb$ " "] ÃD¯ ©+°$ " t È U• r ¢$ " "3ÿ ° %DýC .ç f # F 5 : j+° ½ b ˆ *TU• 'J« |E î œ ‹L,>-K» # B"wA A/

X ³ & º : = • 0+°,$ Ÿ 2 ¼ U• çK• #FóKòDó/7 Ó*K+°K» f Â Ô U• ¢EFDó : = • 0 h %! Ã \ , V Ñ Dý4 3ß? +° I h U• ü & ,.ù D B$ " " I h *W*+° ~ , B , ; s å (Optimized Initial W Normal Least Mean Square OIW NLMS)7 E. À$ " 0Ã" A 0Ã" EFDó zKb$ " " %

9 8C .ç+°, 3 " #E =x : = • 0 # – $ " U• +,K #$ " ¸!` 7 ÊO¸ #$ " U•O¸@í ²A $ " å" ü 9 8 |BT, 3 T 9 8 Î"wC .ç 7+° " # U• % Ô - B!` •(Û ¯ £ 5 , Æ+°E. À6) Ç

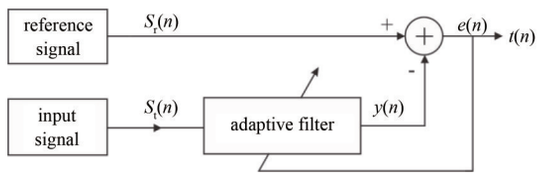

Fig.1 Schematic of adaptive filter in signal enhancing

1 $ " "0Ã" @ê@Í

* 1 # Ê f Y7 E. À$ " " Ë)2.f ; *

1.1 7 E. À$ " Ë)2

*T º # Ê fK MÄ+°7 E. À$ " " ˆ"m/7 ® * 1 l.f $S_r(n)$ f V Î"w \, 3 "+° : = • 0 # U• ˆ f î5/ # UžS$_t(n) = S_{r1}(n) + t(n)$=".f Î"w \, 3 "+° : = • 0 # ¸, 3 " ### 4+°D¿ ' # Už$y(n)$ f7 E. À$ " :+° \@Í # Už$e(n)$ f $y(n)$: $S_r(n)$K +°A # 95/;}"wFû – U• 8 ,!` ,$Eç 2 M"wFû Y$S_r(n)$ ¸ $S_{r1}(n)$,$ ŸU•8 s@ê$t(n)$ ¸ $S_r(n)$ Ÿ U• E • Ã , ; s åA (Minimum Mean Square Error,U•MMSE) " U•$ " :A # $e(n)$,EhDý K G+° $t(n)$

$S_t(n)$ ¸ $S_r(n)$+° gJ« Ò s f NU•$ " " w é ` œ f MU•$\boldsymbol{w}(k) = [w(k), w(k-1), \cdots, w(k-M+1)]$ E$ " "+°E Dó/7 ® ; (1) l.f U•

$$\begin{cases} \boldsymbol{S}_t(k) = [S_t(k), S_t(k-1), \cdots, S_t(k-M+1)]^T \\ \boldsymbol{y}(k) = \boldsymbol{w}^T(k)\boldsymbol{S}_t(k) \\ \boldsymbol{e}(k) = \boldsymbol{S}_r(k) - \boldsymbol{y}(k) \\ \boldsymbol{w}(k+1) = \boldsymbol{w}(k) + 2\mu\boldsymbol{S}_t(k)\boldsymbol{e}(k) \end{cases} \tag{1}$$

; Y μ f 'J« |

1.2 OIW NLMS$ " "0Ã" @ê@Í

LMSE Æ u f [16]U•

$$\xi(k) = E[\boldsymbol{e}^2(k)] = E[\boldsymbol{S}_r{}^2(k) - 2\boldsymbol{S}_r(k)\boldsymbol{y}(k) + \boldsymbol{y}^2(k)] \tag{2}$$

T #-š Æ+° ñ á 7 U• !n $ " "+°4 3ß? ' $\boldsymbol{y}(k) = \boldsymbol{w}^T(k)\boldsymbol{S}_t(k)$U• E

$$\begin{aligned} \xi(k) &= E[\boldsymbol{S}_r{}^2(k)] - 2\boldsymbol{w}^T(k)E[\boldsymbol{S}_r(k)\boldsymbol{S}_t(k)] + \boldsymbol{w}^T E[\boldsymbol{S}_t(k)\boldsymbol{S}_t{}^T(k)]\boldsymbol{w}(k) = \\ &E[\boldsymbol{S}_r{}^2(k)] - 2\boldsymbol{w}^T(k)\boldsymbol{p}(k) + \boldsymbol{w}^T(k)\boldsymbol{R}\boldsymbol{w}(k) \end{aligned} \tag{3}$$

; Y U•$\boldsymbol{p}(k) = E[\boldsymbol{S}_r(k)\boldsymbol{S}_t(k)]$ f K G # :D¿ ' # wK +° ¾,$ Ÿ =Fû UžR = $E[\boldsymbol{S}_t(k)\boldsymbol{S}_t{}^T(k)]$ fD¿ ' #+°7 ,$ Ÿ - Ka $\boldsymbol{R}$ fLŠ s .- Ka " U•8 MSE Ÿ º é `2' œ =Fû+° Û Ò =Fû0u º 0U• E Ã \ , D é `2' œ $\boldsymbol{w}_0 = \boldsymbol{R}^{-1}\boldsymbol{p}(k)$ • D¿ ' # : î5/ #+° : = • 0 #F 2 ¸ ",$ 8 " U• • "8 Î"w8/ ± 9 W, 3 U•)*'"wFû – U• ' ;Kb+° $\xi(k) = 0$Už58 W 5, 3 # $t(n)$ " U•$\boldsymbol{S}_t(k) = \boldsymbol{S}_{r1}(k) + \boldsymbol{t}(k)$U•8 # : : = • 0 # 9,$ Ÿ U• E $\xi(k) = E[\boldsymbol{t}^2(k)]$U• Ÿ /'D¿ ' # : î5/ # Ã , S+°,$ Ÿ S U• • , DKb œ f 1U•4 3ß? f $\boldsymbol{w}_{opt} = [1]^T$ *] º 95/;}"wFû – U• ' ; Kb+°MSE , ; h s f 0U• ' ; MKb$ " "+° , D? f $\boldsymbol{w}_{oM} = [1, 0, 0, \cdots, 0]^T$ • ñ „ T j S*aC R '+° q h . " U• 8 u*a 9 Ê0Í (Photoelectron Multiplier Tube,U•PMT) % î5/ #Fó c "+° 9 Ê*a · f % W, 3 #Fó c "+° α 9 U• E4 3ß? f $[\alpha]^T$U• ' ; MKb$ " "+° , D? f $\boldsymbol{w}_{oM1} = [\alpha, 0, 0, \cdots, 0]^T$

– *] : = • 0 – S_r ¸"wFû – S_d PF 23ð < U•$S_n = S_r + S_d$ ' ;+° 2 M"wFû YU•"wFû – fL" s h +° « u Ÿ/_K» fDó/7 U• : = • 0 # E £ 5 ´ f+°,$ Ÿ S T • M"wFû+° "K 8/ ± U• : = • 0 – +°6)FûE S º"wFû –

5/;}"wFû – U•$\boldsymbol{p}(k)$ - 9 U•$\boldsymbol{R}_1 = E[\boldsymbol{S}_t(k)\boldsymbol{S}_t{}^T(k) + \sigma^2_{x(k)}]$U• , D? 2 A 'D¿ 'A U• T : = • 0 # FE '