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Title Statistical Process Control -- Collection of Some Useful Functions

Author Sven Knoth

Maintainer Sven Knoth <Sven.Knoth@gmx.de>

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Description Evaluation of control charts by means of the zero-state, steady-state ARL (Average Run Length) and RL quantiles. Setting up control charts for given in-control ARL. The control charts under consideration are one- and two-sided EWMA, CUSUM, and Shiryaev-Roberts schemes for monitoring the mean of normally distributed independent data. ARL calculation of the same set of schemes under drift are added. Other charts and parameters are in preparation. Further SPC areas will be covered as well (sampling plans, capability indices ...).

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R topics documented:

dphat	3
lns2ewma.arl	4
lns2ewma.crit	7
mewma.arl	9
mewma.crit	12
mewma.psi	13
p.ewma.arl	14

phat.ewma.arl	16
quadrature.nodes.weights	19
scusum.arl	20
scusum.crit	22
scusums.arl	23
sewma.arl	25
sewma.arl.prerun	27
sewma.crit	29
sewma.crit.prerun	32
sewma.q	34
sewma.q.prerun	36
sewma.sf	38
sewma.sf.prerun	39
tol.lim.fac	40
x.res.ewma.arl	42
xcusum.ad	46
xcusum.arl	48
xcusum.crit	51
xcusum.crit.L0h	53
xcusum.crit.L0L1	54
xcusum.q	56
xcusum.sf	57
xDcusum.arl	58
xDewma.arl	61
xDgrsr.arl	66
xDshewhartrunrules.arl	68
xewma.ad	70
xewma.arl	72
xewma.arl.prerun	78
xewma.crit	81
xewma.q	82
xewma.q.prerun	84
xewma.sf	87
xewma.sf.prerun	89
xgrsr.ad	91
xgrsr.arl	93
xgrsr.crit	96
xsewma.arl	97
xsewma.crit	99
xsewma.q	101
xsewma.sf	103
xshewhart.arl.arl	105
xshewhartrunrules.arl	106
xcusum.arl	109
xtewma.ad	110
xtewma.arl	112
xtewma.q	113
xtewma.sf	115

xtshewhart.ar1.ar1 117

Index **119**

dphat *Percent defective for normal samples*

Description

Density, distribution function and quantile function for the sample percent defective calculated on normal samples with mean equal to μ and standard deviation equal to σ .

Usage

```
dphat(x, n, mu=0, sigma=1, type="known", LSL=-3, USL=3, nodes=30)
```

```
pphat(q, n, mu=0, sigma=1, type="known", LSL=-3, USL=3, nodes=30)
```

```
qphat(p, n, mu=0, sigma=1, type="known", LSL=-3, USL=3, nodes=30)
```

Arguments

x, q	vector of quantiles.
p	vector of probabilities.
n	sample size.
mu, sigma	parameters of the underlying normal distribution.
type	choose whether the standard deviation is given and fixed ("known") or estimated and potentially monitored ("estimated").
LSL, USL	lower and upper specification limit, respectively.
nodes	number of quadrature nodes needed for type="estimated".

Details

Bruhn-Suhr/Krumbholz (1990) derived the cumulative distribution function of the sample percent defective calculated on normal samples to applying them for a new variables sampling plan. These results were heavily used in Krumbholz/Zöllner (1995) for Shewhart and in Knoth/Steinmetz (2013) for EWMA control charts. For algorithmic details see, essentially, Bruhn-Suhr/Krumbholz (1990). Two design variants are treated: The simple case, type="known", with known normal variance and the presumably much more relevant and considerably intricate case, type="estimated", where both parameters of the normal distribution are unknown. Basically, given lower and upper specification limits and the normal distribution, one estimates the expected yield based on a normal sample of size n .

Value

Returns vector of pdf, cdf or qf values for the statistic phat.

Author(s)

Sven Knoth

References

- M. Bruhn-Suhr and W. Krumbholz (1990), A new variables sampling plan for normally distributed lots with unknown standard deviation and double specification limits, *Statistical Papers* 31(1), 195-207.
- W. Krumbholz and A. Zöllner (1995), p-Karten vom Shewhartschen Typ für die messende Prüfung, *Allgemeines Statistisches Archiv* 79, 347-360.
- S. Knoth and S. Steinmetz (2013), EWMA p charts under sampling by variables, *International Journal of Production Research* 51(13), 3795-3807.

See Also

phat.ewma.ar1 for routines using the herewith considered phat statistic.

Examples

```
# Figures 1 (c) and (d) from Knoth/Steinmetz (2013)
n      <- 5
LSL    <- -3
USL    <- 3

par(mar=c(5, 5, 1, 1) + 0.1)

p.star <- 2*pnorm( (LSL-USL)/2 ) # for p <= p.star pdf and cdf vanish

p_ <- seq(p.star+1e-10, 0.07, 0.0001) # define support of Figure 1

# Figure 1 (c)
pp_ <- pphat(p_, n)
plot(p_, pp_, type="l", xlab="p", ylab=expression(P( hat(p) <= p )),
      xlim=c(0, 0.06), ylim=c(0,1), lwd=2)
abline(h=0:1, v=p.star, col="grey")

# Figure 1 (d)
dp_ <- dphat(p_, n)
plot(p_, dp_, type="l", xlab="p", ylab="f(p)", xlim=c(0, 0.06),
      ylim=c(0,50), lwd=2)
abline(h=0, v=p.star, col="grey")
```

 Ins2ewma.ar1

 Compute ARLs of EWMA in S^2 control charts (variance charts)

Description

Computation of the (zero-state) Average Run Length (ARL) for different types of EWMA control charts (based on the log of the sample variance S^2) monitoring normal variance.

Usage

```
Ins2ewma.arl(l,c1,cu,sigma,df,hs=NULL,sided="upper",r=40)
```

Arguments

l	smoothing parameter lambda of the EWMA control chart.
c1	lower control limit of the EWMA control chart.
cu	upper control limit of the EWMA control chart.
sigma	true standard deviation.
df	actual degrees of freedom, corresponds to subsample size (for known mean it is equal to the subsample size, for unknown mean it is equal to subsample size minus one.
hs	so-called headstart (enables fast initial response) – the default value (hs=NULL) corresponds to the in-control mean of $\ln S^2$.
sided	distinguishes between one- and two-sided two-sided EWMA- S^2 control charts by choosing "upper" (upper chart with reflection at c1), "lower" (lower chart with reflection at cu), and "two" (two-sided chart), respectively.
r	dimension of the resulting linear equation system: the larger the better.

Details

Ins2ewma.arl determines the Average Run Length (ARL) by numerically solving the related ARL integral equation by means of the Nystroem method based on Gauss-Legendre quadrature.

Value

Returns a single value which resembles the ARL.

Author(s)

Sven Knoth

References

S. V. Crowder and M. D. Hamilton (1992), An EWMA for monitoring a process standard deviation, *Journal of Quality Technology* 24, 12-21.

S. Knoth (2005), Accurate ARL computation for EWMA- S^2 control charts, *Statistics and Computing* 15, 341-352.

See Also

xewma.arl for zero-state ARL computation of EWMA control charts for monitoring normal mean.

Examples

```

lns2ewma.ARL <- Vectorize("lns2ewma.arl", "sigma")

## Crowder/Hamilton (1992)
## moments of ln S^2
E_log_gamma <- function(df) log(2/df) + digamma(df/2)
V_log_gamma <- function(df) trigamma(df/2)
E_log_gamma_approx <- function(df) -1/df - 1/3/df^2 + 2/15/df^4
V_log_gamma_approx <- function(df) 2/df + 2/df^2 + 4/3/df^3 - 16/15/df^5

## results from Table 3 ( upper chart with reflection at  $\theta = \log(\sigma\theta=1)$  )
## original entries are (lambda = 0.05, K = 1.06, df=n-1=4)
# sigma  ARL
# 1      200
# 1.1    43
# 1.2    18
# 1.3    11
# 1.4     7.6
# 1.5     6.0
# 2       3.2

df <- 4
lambda <- .05
K <- 1.06
cu <- K * sqrt( lambda/(2-lambda) * V_log_gamma_approx(df) )

sigmas <- c(1 + (0:5)/10, 2)
arls <- round(lns2ewma.ARL(lambda, 0, cu, sigmas, df, hs=0, sided="upper"), digits=1)
data.frame(sigmas, arls)

## Knoth (2005)
## compare with Table 3 (p. 351)
lambda <- .05
df <- 4
K <- 1.05521
cu <- 1.05521 * sqrt( lambda/(2-lambda) * V_log_gamma_approx(df) )

## upper chart with reflection at sigma0=1 in Table 4
## original entries are
# sigma  ARL_0  ARL_-.267
# 1      200.0  200.0
# 1.1    43.04  41.55
# 1.2    18.10  19.92
# 1.3    10.75  13.11
# 1.4     7.63  9.93
# 1.5     5.97  8.11
# 2       3.17  4.67

M <- -0.267
cuM <- lns2ewma.crit(lambda, 200, df, cl=M, hs=M, r=60)[2]
arls1 <- round(lns2ewma.ARL(lambda, 0, cu, sigmas, df, hs=0, sided="upper"), digits=2)
arls2 <- round(lns2ewma.ARL(lambda, M, cuM, sigmas, df, hs=M, sided="upper", r=60), digits=2)

```

```
data.frame(sigmas, arls1, arls2)
```

Ins2ewma.crit	<i>Compute critical values of EWMA In S^2 control charts (variance charts)</i>
---------------	---

Description

Computation of the critical values (similar to alarm limits) for different types of EWMA control charts (based on the log of the sample variance S^2) monitoring normal variance.

Usage

```
Ins2ewma.crit(l,L0,df,sigma0=1,c1=NULL,cu=NULL,hs=NULL,sided="upper",mode="fixed",r=40)
```

Arguments

<code>l</code>	smoothing parameter lambda of the EWMA control chart.
<code>L0</code>	in-control ARL.
<code>df</code>	actual degrees of freedom, corresponds to subsample size (for known mean it is equal to the subsample size, for unknown mean it is equal to subsample size minus one).
<code>sigma0</code>	in-control standard deviation.
<code>c1</code>	deployed for <code>sided="upper"</code> , that is, upper variance control chart with lower reflecting barrier <code>c1</code> .
<code>cu</code>	for two-sided (<code>sided="two"</code>) and fixed upper control limit (<code>mode="fixed"</code>), for all other cases <code>cu</code> is ignored.
<code>hs</code>	so-called headstart (enables fast initial response) – the default value (<code>hs=NULL</code>) corresponds to the in-control mean of $\ln S^2$.
<code>sided</code>	distinguishes between one- and two-sided two-sided EWMA- S^2 control charts by choosing "upper" (upper chart with reflection at <code>c1</code>), "lower" (lower chart with reflection at <code>cu</code>), and "two" (two-sided chart), respectively.
<code>mode</code>	only deployed for <code>sided="two"</code> – with "fixed" an upper control limit (see <code>cu</code>) is set and only the lower is calculated to obtain the in-control ARL <code>L0</code> , while with "unbiased" a certain unbiasedness of the ARL function is guaranteed (here, both the lower and the upper control limit are calculated). With "vanilla" limits symmetric around the in-control mean of $\ln S^2$ are determined, while for "eq.tails" the in-control ARL values of two single EWMA variance charts (decompose the two-sided scheme into one lower and one upper scheme) are matched.
<code>r</code>	dimension of the resulting linear equation system: the larger the more accurate.

Details

Ins2ewma.crit determines the critical values (similar to alarm limits) for given in-control ARL L_0 by applying secant rule and using Ins2ewma.arl(). In case of sided="two" and mode="unbiased" a two-dimensional secant rule is applied that also ensures that the maximum of the ARL function for given standard deviation is attained at σ_0 . See Knoth (2010) and the related example.

Value

Returns the lower and upper control limit c1 and cu.

Author(s)

Sven Knoth

References

C. A. Acosta-Mejía and J. J. Pignatiello Jr. and B. V. Rao (1999), A comparison of control charting procedures for monitoring process dispersion, *IIE Transactions* 31, 569-579.

S. V. Crowder and M. D. Hamilton (1992), An EWMA for monitoring a process standard deviation, *Journal of Quality Technology* 24, 12-21.

S. Knoth (2005), Accurate ARL computation for EWMA- S^2 control charts, *Statistics and Computing* 15, 341-352.

S. Knoth (2010), Control Charting Normal Variance – Reflections, Curiosities, and Recommendations, in *Frontiers in Statistical Quality Control* 9, H.-J. Lenz and P.-T. Wilrich (Eds.), Physica Verlag, Heidelberg, Germany, 3-18.

See Also

Ins2ewma.arl for calculation of ARL of EWMA in S^2 control charts.

Examples

```
## Knoth (2005)
## compare with Table 3 (p. 351)
L0 <- 200
l <- .05
df <- 4
limits <- Ins2ewma.crit(l, L0, df, c1=0, hs=0)
limits["cu"]
```


mewma.arl

*Compute ARLs of MEWMA control charts***Description**

Computation of the (zero-state) Average Run Length (ARL) for multivariate exponentially weighted moving average (MEWMA) charts monitoring multivariate normal mean.

Usage

```
mewma.arl(l, cE, p, delta=0, hs=0, r=20, ntype=NULL, qm0=20, qm1=qm0)
```

```
mewma.arl.f(l, cE, p, delta=0, r=20, ntype=NULL, qm0=20, qm1=qm0)
```

```
mewma.ad(l, cE, p, delta=0, r=20, n=20, type="cond", hs=0, ntype=NULL, qm0=20, qm1=qm0)
```

Arguments

l	smoothing parameter lambda of the MEWMA control chart.
cE	alarm threshold of the MEWMA control chart.
p	dimension of multivariate normal distribution.
delta	magnitude of the potential change, delta=0 refers to the in-control state.
hs	so-called headstart (enables fast initial response) – must be non-negative.
r	number of quadrature nodes – dimension of the resulting linear equation system for delta = 0. For non-zero delta this dimension is mostly r^2 (Markov chain approximation leads to some larger values). Caution: If ntype is set to "co" (collocation), then values of r larger than 20 lead to large computing times. For the other selections this would happen for values larger than 40.
ntype	choose the numerical algorithm to solve the ARL integral equation. For delta=0: Possible values are "g1", "g12" (gauss-legendre, classic and with variables change: square), "co" (collocation, for delta > 0 with sin transformation), "ra" (radau), "cc" (clenshaw-curtis), "mc" (markov chain), and "sr" (simpson rule). For delta larger than 0, some more values besides the others are possible: "g13", "g14", "g15" (gauss-legendre with a further change in variables: sin, tan, sinh), "co2", "co3" (collocation with some trimming and tan as quadrature stabilizing transformations, respectively). If it is set to NULL (the default), then for delta=0 then "g12" is chosen. If delta larger than 0, then for p equal 2 or 4 "g13" and for all other values "g15" is taken. "ra" denotes the method used in Rigdon (1995a). "mc" denotes the Markov chain approximation.
type	switch between "cond" and "cycl" for differentiating between the conditional (no false alarm) and the cyclical (after false alarm re-start in hs), respectively.
n	number of quadrature nodes for Calculating the steady-state ARL integral(s).
qm0, qm1	number of collocation quadrature nodes for the out-of-control case (qm0 for the inner integral, qm1 for the outer one), that is, for positive delta, and for the in-control case (now only qm0 is deployed) if via ntype the collocation procedure is requested.

Details

Basically, this is the implementation of different numerical algorithms for solving the integral equation for the MEWMA in-control ($\delta = 0$) ARL introduced in Rigdon (1995a) and out-of-control ($\delta \neq 0$) ARL in Rigdon (1995b). Most of them are nothing else than the Nystroem approach – the integral is replaced by a suitable quadrature. Here, the Gauss-Legendre (more powerful), Radau (used by Rigdon, 1995a), Clenshaw-Curtis, and Simpson rule (which is really bad) are provided. Additionally, the collocation approach is offered as well, because it is much better for small odd values for p . FORTRAN code for the Radau quadrature based Nystroem of Rigdon (1995a) was published in Bodden and Rigdon (1999) – see also <http://lib.stat.cmu.edu/jqt/31-1>. Furthermore, FORTRAN code for the Markov chain approximation (in- and out-of-control) could be found at

<http://lib.stat.cmu.edu/jqt/33-4>. The related papers are Runger and Prabhu (1996) and Molnau et al. (2001). The idea of the Clenshaw-Curtis quadrature was taken from Capizzi and Masarotto (2010), who successfully deployed a modified Clenshaw-Curtis quadrature to calculate the ARL of combined (univariate) Shewhart-EWMA charts. It turns out that it works also nicely for the MEWMA ARL. The version `mewma.arl.f()` without the argument `hs` provides the ARL as function of one (in-control) or two (out-of-control) arguments.

Value

Returns a single value which is simply the zero-state ARL.

Author(s)

Sven Knoth

References

- Kevin M. Bodden and Steven E. Rigdon (1999), A program for approximating the in-control ARL for the MEWMA chart, *Journal of Quality Technology* 31, 120-123.
- Giovanna Capizzi and Guido Masarotto (2010), Evaluation of the run-length distribution for a combined Shewhart-EWMA control chart, *Statistics and Computing* 20, 23-33.
- Sven Knoth (2017), ARL Numerics for MEWMA Charts, *Journal of Quality Technology* 49, 78-89.
- Wade E. Molnau et al. (2001), A Program for ARL Calculation for Multivariate EWMA Charts, *Journal of Quality Technology* 33, 515-521.
- Steven E. Rigdon (1995a), An integral equation for the in-control average run length of a multivariate exponentially weighted moving average control chart, *J. Stat. Comput. Simulation* 52, 351-365.
- Steven E. Rigdon (1995b), A double-integral equation for the average run length of a multivariate exponentially weighted moving average control chart, *Stat. Probab. Lett.* 24, 365-373.
- George C. Runger and Sharad S. Prabhu (1996), A Markov Chain Model for the Multivariate Exponentially Weighted Moving Averages Control Chart, *J. Amer. Statist. Assoc.* 91, 1701-1706.

See Also

`mewma.crit` for getting the alarm threshold to attain a certain in-control ARL.

Examples

```

# Rigdon (1995b), p. 372, Tab. 1
r <- 0.1
p <- 4
h <- 12.73
L0a <- mewma.arl(r, h, p) # defaults to "gl2" because of the even p.
L0b <- mewma.arl(r, h, p, ntype="co")
L0c <- mewma.arl(r, h, p, r=48, ntype="ra")
L0d <- mewma.arl(r, h, p, ntype="cc")
L0e <- mewma.arl(r, h, p, ntype="mc")
data.frame(L0a, L0b, L0c, L0d, L0e)

# original (Rigdon 1995a) implicite value is 200
p <- 3
h <- 10.81
L0a <- mewma.arl(r, h, p, ntype="gl2")
L0aa <- mewma.arl(r, h, p, r=48, ntype="gl2")
L0b <- mewma.arl(r, h, p, ntype="co")
L0bb <- mewma.arl(r, h, p, r=48, ntype="co")
L0c <- mewma.arl(r, h, p, r=48, ntype="ra")
L0d <- mewma.arl(r, h, p, ntype="cc")
L0dd <- mewma.arl(r, h, p, r=48, ntype="cc")
L0e <- mewma.arl(r, h, p, ntype="mc")
L0ee <- mewma.arl(r, h, p, r=48, ntype="mc")
data.frame(L0a, L0aa, L0b, L0bb, L0c, L0d, L0dd, L0e, L0ee)
# original (Rigdon 1995a) implicite value is 1000

# Rigdon (1995b), p. 372, Tab. 1
p <- 5
h <- 14.56
L1 <- mewma.arl(r, h, p, delta=1, r=20)
L1
# original value is 12.9

# Knoth (2017), p. 85, Tab. 3, rows with p=3
## Not run:
p <- 3
lambda <- 0.05
h4 <- mewma.crit(lambda, 200, p)
benchmark <- mewma.arl(lambda, h4, p, delta=1, r=50)

mc.arl <- mewma.arl(lambda, h4, p, delta=1, r=25, ntype="mc")
ra.arl <- mewma.arl(lambda, h4, p, delta=1, r=27, ntype="ra")
co.arl <- mewma.arl(lambda, h4, p, delta=1, r=12, ntype="co2")
gl3.arl <- mewma.arl(lambda, h4, p, delta=1, r=30, ntype="gl3")
gl5.arl <- mewma.arl(lambda, h4, p, delta=1, r=25, ntype="gl5")

abs( benchmark - data.frame(mc.arl, ra.arl, co.arl, gl3.arl, gl5.arl) )
## End(Not run)

```

`mewma.crit`*Compute alarm threshold of MEWMA control charts*

Description

Computation of the alarm threshold for multivariate exponentially weighted moving average (MEWMA) charts monitoring multivariate normal mean.

Usage

```
mewma.crit(l, L0, p, hs=0, r=20)
```

Arguments

<code>l</code>	smoothing parameter lambda of the MEWMA control chart.
<code>L0</code>	in-control ARL.
<code>p</code>	dimension of multivariate normal distribution.
<code>hs</code>	so-called headstart (enables fast initial response) – must be non-negative.
<code>r</code>	number of quadrature nodes – dimension of the resulting linear equation system.

Details

`mewma.crit` determines the alarm threshold of for given in-control ARL `L0` by applying secant rule and using `mewma.arl()` with `ntype="g12"`.

Value

Returns a single value which resembles the critical value `c`.

Author(s)

Sven Knoth

References

Sven Knoth (2017), ARL Numerics for MEWMA Charts, *Journal of Quality Technology* 49, 78-89.
Steven E. Rigdon (1995), An integral equation for the in-control average run length of a multivariate exponentially weighted moving average control chart, *J. Stat. Comput. Simulation* 52, 351-365.

See Also

`mewma.arl` for zero-state ARL computation.

Examples

```

# Rigdon (1995), p. 358, Tab. 1
p <- 4
L0 <- 500
r <- .25
h4 <- mewma.crit(r, L0, p)
h4
## original value is 16.38.

# Knoth (2017), p. 82, Tab. 2
p <- 3
L0 <- 1e3
lambda <- c(0.25, 0.2, 0.15, 0.1, 0.05)
h4 <- rep(NA, length(lambda) )
for ( i in 1:length(lambda) ) h4[i] <- mewma.crit(lambda[i], L0, p, r=20)
round(h4, digits=2)
## original values are
## 15.82 15.62 15.31 14.76 13.60

```

mewma.psi

Compute steady-state density of the MEWMA statistic

Description

Computation of the (zero-state) steady-state density function of the statistic deployed in multivariate exponentially weighted moving average (MEWMA) charts monitoring multivariate normal mean.

Usage

```
mewma.psi(l, cE, p, type="cond", hs=0, r=20)
```

Arguments

l	smoothing parameter lambda of the MEWMA control chart.
cE	alarm threshold of the MEWMA control chart.
p	dimension of multivariate normal distribution.
type	switch between "cond" and "cycl" for differentiating between the conditional (no false alarm) and the cyclical (after false alarm re-start in hs), respectively.
hs	the re-starting point for the cyclical steady-state framework.
r	number of quadrature nodes.

Details

Basically, ideas from Knoth (2015, MEWMA numerics) and Knoth (2014, steady-state ARL concepts) are merged. More details will follow.

Value

Returns a function.

Author(s)

Sven Knoth

References

Sven Knoth (2014), The Case Against the Use of Synthetic Control Charts, accepted in *Journal of Quality Technology*.

Sven Knoth (2017), ARL Numerics for MEWMA Charts, *Journal of Quality Technology* 49, 78-89.

Sven Knoth (2017), Calculating the Steady-State ARL of MEWMA Control Charts, unpublished manuscript.

See Also

mewma.arl for calculating the in-control ARL of MEWMA.

Examples

```
lambda <- 0.1
L0 <- 1000
p <- 3
h4 <- mewma.crit(lambda, L0, p)
x_ <- seq(0, h4*lambda/(2-lambda), by=0.002)
psi <- mewma.psi(lambda, h4, p)
psi_ <- psi(x_)
#plot(x_, psi_, type="l", xlab="x", ylab=expression(psi(x)))
```

p.ewma.arl

Compute ARLs of binomial EWMA p control charts

Description

Computation of the (zero-state) Average Run Length (ARL) at given rate p.

Usage

```
p.ewma.arl(lambda, ucl, n, p, z0, d.res=1, r.mode="ieee.round", i.mode="integer")
```

Arguments

lambda	smoothing parameter of the EWMA p control chart.
ucl	upper control limit of the EWMA p control chart.
n	subgroup size.
p	(failure/success) rate.
z0	so-called headstart (give fast initial response).
d.res	resolution (see details).
r.mode	round mode – allowed modes are "gan.floor", "floor", "ceil", "ieee.round", "round", "mix".
i.mode	type of interval center – "integer" or "half" integer.

Details

The monitored data follow a binomial distribution with size n and failure/success probability p . The ARL values of the resulting EWMA control chart are determined by Markov chain approximation. Here, the original EWMA values are approximated by multiples of one over $d.res$. Different ways of rounding (see `r.mode`) to the next multiple are implemented. Besides Gan's paper nothing is published about the numerical subtleties.

Value

Return single value which resemble the ARL.

Author(s)

Sven Knoth

References

- F. F. Gan (1990), Monitoring observations generated from a binomial distribution using modified exponentially weighted moving average control chart, *J. Stat. Comput. Simulation* 37, 45-60.
- S. Knoth and S. Steinmetz (2013), EWMA p charts under sampling by variables, *International Journal of Production Research* 51, 3795-3807.

See Also

later.

Examples

```
## Gan (1990)

# Table 1

n <- 150
p0 <- .1
z0 <- n*p0
```

```

lambda <- c(1, .51, .165)
hu <- c(27, 22, 18)

p.value <- .1 + (0:20)/200

p.EWMA.arl <- Vectorize(p.ewma.arl, "p")

arl1.value <- round(p.EWMA.arl(lambda[1], hu[1], n, p.value, z0, r.mode="round"), digits=2)
arl2.value <- round(p.EWMA.arl(lambda[2], hu[2], n, p.value, z0, r.mode="round"), digits=2)
arl3.value <- round(p.EWMA.arl(lambda[3], hu[3], n, p.value, z0, r.mode="round"), digits=2)

arls <- matrix(c(arl1.value, arl2.value, arl3.value), ncol=length(lambda))
rownames(arls) <- p.value
colnames(arls) <- paste("lambda =", lambda)
arls

## Knoth/Steinmetz (2013)

n <- 5
p0 <- 0.02
z0 <- n*p0
lambda <- 0.3
ucl <- 0.649169922 ## in-control ARL 370.4 (determined with d.res = 2^14 = 16384)

res.list <- 2^(1:12)
arl.list <- NULL
for ( res in res.list ) {
  arl <- p.ewma.arl(lambda, ucl, n, p0, z0, d.res=res)
  arl.list <- c(arl.list, arl)
}
cbind(res.list, arl.list)

```

phat.ewma.arl

Compute ARLs of EWMA phat control charts

Description

Computation of the (zero-state) Average Run Length (ARL), upper control limit (ucl) for given in-control ARL, and lambda for minimal out-of control ARL at given shift.

Usage

```
phat.ewma.arl(lambda, ucl, mu, n, z0, sigma=1, type="known", LSL=-3, USL=3, N=15,
qm=25, ntype="coll")
```

```
phat.ewma.crit(lambda, L0, mu, n, z0, sigma=1, type="known", LSL=-3, USL=3, N=15, qm=25)
```

```
phat.ewma.lambda(L0, mu, n, z0, sigma=1, type="known", max_l=1, min_l=.001, LSL=-3, USL=3,
qm=25)
```


Arguments

lambda	smoothing parameter of the EWMA control chart.
ucl	upper control limit of the EWMA phat control chart.
L0	pre-defined in-control ARL (Average Run Length).
mu	true mean or mean where the ARL should be minimized (then the in-control mean is simply 0).
n	subgroup size.
z0	so-called headstart (gives fast initial response).
type	choose whether the standard deviation is given and fixed ("known") or estimated and potentially monitored ("estimated").
sigma	actual standard deviation of the data – the in-control value is 1.
max_l, min_l	maximal and minimal value for optimal lambda search.
LSL, USL	lower and upper specification limit, respectively.
N	size of collocation base, dimension of the resulting linear equation system is equal to N.
qm	number of nodes for collocation quadratures.
ntype	switch between the default method coll (collocation) and the classic one markov (Markov chain approximation) for calculating the ARL numerically.

Details

The three implemented functions allow to apply a new type control chart. Basically, lower and upper specification limits are given. The monitoring vehicle then is the empirical probability that an item will not follow these specification given the sequence of sample means. If the related EWMA sequence violates the control limits, then the alarm indicates a significant process deterioration. For details see the paper mentioned in the references. To be able to construct the control charts, see the first example.

Value

Return single values which resemble the ARL, the critical value, and the optimal lambda, respectively.

Author(s)

Sven Knoth

References

S. Knoth and S. Steinmetz (2013), EWMA p charts under sampling by variables, *International Journal of Production Research* 51, 3795-3807.

See Also

sewma.arl for a further collocation based ARL calculation routine.

Examples

```
## Simple example to demonstrate the chart.

# some functions
h.mu <- function(mu) pnorm(LSL-mu) + pnorm(mu-USL)
ewma <- function(x, lambda=0.1, z0=0) filter(lambda*x, 1-lambda, m="r", init=z0)

# parameters
LSL <- -3      # lower specification limit
USL <- 3      # upper specification limit
n <- 5        # batch size
lambda <- 0.1 # EWMA smoothing parameter
L0 <- 1000    # in-control Average Run Length (ARL)
z0 <- h.mu(0) # start at minimal defect level
ucl <- phat.ewma.crit(lambda, L0, 0, n, z0, LSL=LSL, USL=USL)

# data
x0 <- matrix(rnorm(50*n), ncol=5) # in-control data
x1 <- matrix(rnorm(50*n, mean=0.5), ncol=5) # out-of-control data
x <- rbind(x0,x1) # all data

# create chart
xbar <- apply(x, 1, mean)
phat <- h.mu(xbar)
z <- ewma(phat, lambda=lambda, z0=z0)
plot(1:length(z), z, type="l", xlab="batch", ylim=c(0,.02))
abline(h=z0, col="grey", lwd=.7)
abline(h=ucl, col="red")

## S. Knoth, S. Steinmetz (2013)

# Table 1

lambdas <- c(.5, .25, .2, .1)
L0 <- 370.4
n <- 5
LSL <- -3
USL <- 3

phat.ewma.CRIT <- Vectorize("phat.ewma.crit", "lambda")
p.star <- pnorm( LSL ) + pnorm( -USL ) ## lower bound of the chart
ucls <- phat.ewma.CRIT(lambdas, L0, 0, n, p.star, LSL=LSL, USL=USL)
print(cbind(lambdas, ucls))

# Table 2

mus <- c((0:4)/4, 1.5, 2, 3)
phat.ewma.ARL <- Vectorize("phat.ewma.arl", "mu")
arls <- NULL
for ( i in 1:length(lambdas) ) {
  arls <- cbind(arls, round(phat.ewma.ARL(lambdas[i], ucls[i], mus,
```

```
      n, p.star, LSL=LSL, USL=USL), digits=2))
}
arls <- data.frame(arls, row.names=NULL)
names(arls) <- lambdas
print(arls)

# Table 3

## Not run:
mus <- c(.25, .5, 1, 2)
phat.ewma.LAMBDA <- Vectorize("phat.ewma.lambda", "mu")
lambdas <- phat.ewma.LAMBDA(L0, mus, n, p.star, LSL=LSL, USL=USL)
print(cbind(mus, lambdas))
## End(Not run)
```

quadrature.nodes.weights

Calculate quadrature nodes and weights

Description

Computation of the nodes and weights to enable numerical quadrature.

Usage

```
quadrature.nodes.weights(n, type="GL", x1=-1, x2=1)
```

Arguments

n	number of nodes (and weights).
type	quadrature type – currently Gauss-Legendre, "GL", and Radau, "Ra", are supported.
x1	lower limit of the integration interval.
x2	upper limit of the integration interval.

Details

A more detailed description will follow soon. The algorithm for the Gauss-Legendre quadrature was delivered by Knut Petras to me, while the one for the Radau quadrature was taken from John Burkardt.

Value

Returns two vectors which hold the needed quadrature nodes and weights.

Author(s)

Sven Knoth

References

H. Brass and K. Petras (2011), *Quadrature Theory. The Theory of Numerical Integration on a Compact Interval*, Mathematical Surveys and Monographs, American Mathematical Society.

See Also

Many of the ARL routines use the Gauss-Legendre nodes.

Examples

```
# GL
n <- 10
qmw <-quadrature.nodes.weights(n, type="GL")
qmw

# Radau
n <- 10
qmw <-quadrature.nodes.weights(n, type="Ra")
qmw
```

scusum.arl

Compute ARLs of CUSUM control charts (variance charts)

Description

Computation of the (zero-state) Average Run Length (ARL) for different types of CUSUM control charts (based on the sample variance S^2) monitoring normal variance.

Usage

```
scusum.arl(k, h, sigma, df, hs=0, sided="upper", k2=NULL,
h2=NULL, hs2=0, r=40, qm=30, version=2)
```

Arguments

k	reference value of the CUSUM control chart.
h	decision interval (alarm limit, threshold) of the CUSUM control chart.
sigma	true standard deviation.
df	actual degrees of freedom, corresponds to subgroup size (for known mean it is equal to the subgroup size, for unknown mean it is equal to subgroup size minus one).
hs	so-called headstart (enables fast initial response).
sided	distinguishes between one- and two-sided two-sided CUSUM- S^2 control charts by choosing "upper" (upper chart), "lower" (lower chart), and "two" (two-sided chart), respectively. Note that for the two-sided chart the parameters "k2" and "h2" have to be set too.

k2	In case of a two-sided CUSUM chart for variance the reference value of the lower chart.
h2	In case of a two-sided CUSUM chart for variance the decision interval of the lower chart.
hs2	In case of a two-sided CUSUM chart for variance the headstart of the lower chart.
r	Dimension of the resulting linear equation system (highest order of the collocation polynomials times number of intervals – see Knoth 2006).
qm	Number of quadrature nodes for calculating the collocation definite integrals.
version	Distinguish version numbers (1,2,...). For internal use only.

Details

scusum.ar1 determines the Average Run Length (ARL) by numerically solving the related ARL integral equation by means of collocation (piecewise Chebyshev polynomials).

Value

Returns a single value which resembles the ARL.

Author(s)

Sven Knoth

References

S. Knoth (2005), Accurate ARL computation for EWMA- S^2 control charts, *Statistics and Computing* 15, 341-352.

S. Knoth (2006), Computation of the ARL for CUSUM- S^2 schemes, *Computational Statistics & Data Analysis* 51, 499-512.

See Also

xcusum.ar1 for zero-state ARL computation of CUSUM control charts for monitoring normal mean.

Examples

```
## Knoth (2006)
## compare with Table 1 (p. 507)
k <- 1.46 # sigma1 = 1.5
df <- 1
h <- 10

# original values
# sigma coll63      BE      Hawkins  MC 10^9 (s.e.)
# 1      260.7369  260.7546  261.32  260.7399 (0.0081)
# 1.1    90.1319   90.1389   90.31   90.1319 (0.0027)
# 1.2    43.6867   43.6897   43.75   43.6845 (0.0013)
```

```
# 1.3    26.2916   26.2932   26.32   26.2929 (0.0007)
# 1.4    18.1231   18.1239   18.14   18.1235 (0.0005)
# 1.5    13.6268   13.6273   13.64   13.6272 (0.0003)
# 2      5.9904    5.9910    5.99    5.9903 (0.0001)
# replicate the column coll63
sigma <- c(1, 1.1, 1.2, 1.3, 1.4, 1.5, 2)
arl <- rep(NA, length(sigma))
for ( i in 1:length(sigma) )
  arl[i] <- round(scusum.arl(k, h, sigma[i], df, r=63, qm=20, version=2), digits=4)
data.frame(sigma, arl)
```

scusum.crit	<i>Compute decision intervals of CUSUM control charts (variance charts)</i>
-------------	---

Description

omputation of the decision intervals (alarm limits) for different types of CUSUM control charts (based on the sample variance S^2) monitoring normal variance.

Usage

```
scusum.crit(k, L0, sigma, df, hs=0, sided="upper", mode="eq.tails",
k2=NULL, hs2=0, r=40, qm=30)
```

Arguments

k	reference value of the CUSUM control chart.
L0	in-control ARL.
sigma	true standard deviation.
df	actual degrees of freedom, corresponds to subgroup size (for known mean it is equal to the subgroup size, for unknown mean it is equal to subgroup size minus one).
hs	so-called headstart (enables fast initial response).
sided	distinguishes between one- and two-sided two-sided CUSUM- S^2 control charts by choosing "upper" (upper chart), "lower" (lower chart), and "two" (two-sided chart), respectively. Note that for the two-sided chart the parameters "k2" and "h2" have to be set too.
mode	only deployed for sided="two" – with "eq.tails" two one-sided CUSUM charts (lower and upper) with the same in-control ARL are coupled. With "unbiased" a certain unbiasedness of the ARL function is guaranteed (here, both the lower and the upper control limit are calculated).
k2	in case of a two-sided CUSUM chart for variance the reference value of the lower chart.
hs2	in case of a two-sided CUSUM chart for variance the headstart of the lower chart.

r	Dimension of the resulting linear equation system (highest order of the collocation polynomials times number of intervals – see Knoth 2006).
qm	Number of quadrature nodes for calculating the collocation definite integrals.

Details

scusum.crit determines the decision interval (alarm limit) for given in-control ARL L_0 by applying secant rule and using scusum.arl().

Value

Returns a single value which resembles the decision interval h.

Author(s)

Sven Knoth

References

S. Knoth (2005), Accurate ARL computation for EWMA- S^2 control charts, *Statistics and Computing* 15, 341-352.

S. Knoth (2006), Computation of the ARL for CUSUM- S^2 schemes, *Computational Statistics & Data Analysis* 51, 499-512.

See Also

xcusum.arl for zero-state ARL computation of CUSUM control charts monitoring normal mean.

Examples

```
## Knoth (2006)
## compare with Table 1 (p. 507)
k <- 1.46 # sigma1 = 1.5
df <- 1
L0 <- 260.74
h <- scusum.crit(k, L0, 1, df)
h
# original value is 10
```

scusums.arl

Compute ARLs of CUSUM-Shewhart control charts (variance charts)

Description

Computation of the (zero-state) Average Run Length (ARL) for different types of CUSUM-Shewhart combo control charts (based on the sample variance S^2) monitoring normal variance.

Usage

```
scusums.arl(k, h, cS, sigma, df, hs=0, sided="upper", k2=NULL,
h2=NULL, hs2=0, r=40, qm=30, version=2)
```

Arguments

k	reference value of the CUSUM control chart.
h	decision interval (alarm limit, threshold) of the CUSUM control chart.
cS	Shewhart limit.
sigma	true standard deviation.
df	actual degrees of freedom, corresponds to subgroup size (for known mean it is equal to the subgroup size, for unknown mean it is equal to subgroup size minus one).
hs	so-called headstart (enables fast initial response).
sided	distinguishes between one- and two-sided two-sided CUSUM- S^2 control charts by choosing "upper" (upper chart), "lower" (lower chart), and "two" (two-sided chart), respectively. Note that for the two-sided chart the parameters "k2" and "h2" have to be set too.
k2	In case of a two-sided CUSUM chart for variance the reference value of the lower chart.
h2	In case of a two-sided CUSUM chart for variance the decision interval of the lower chart.
hs2	In case of a two-sided CUSUM chart for variance the headstart of the lower chart.
r	Dimension of the resulting linear equation system (highest order of the collocation polynomials times number of intervals – see Knoth 2006).
qm	Number of quadrature nodes for calculating the collocation definite integrals.
version	Distinguish version numbers (1,2,...). For internal use only.

Details

scusums.arl determines the Average Run Length (ARL) by numerically solving the related ARL integral equation by means of collocation (piecewise Chebyshev polynomials).

Value

Returns a single value which resembles the ARL.

Author(s)

Sven Knoth

References

S. Knoth (2006), Computation of the ARL for CUSUM- S^2 schemes, *Computational Statistics & Data Analysis* 51, 499-512.

See Also

scusum.arl for zero-state ARL computation of standalone CUSUM control charts for monitoring normal variance.

Examples

```
## will follow
```

```
sewma.arl
```

Compute ARLs of EWMA control charts (variance charts)

Description

Computation of the (zero-state) Average Run Length (ARL) for different types of EWMA control charts (based on the sample variance S^2) monitoring normal variance.

Usage

```
sewma.arl(l, c1, cu, sigma, df, s2.on=TRUE, hs=NULL, sided="upper", r=40, qm=30)
```

Arguments

l	smoothing parameter lambda of the EWMA control chart.
c1	lower control limit of the EWMA control chart.
cu	upper control limit of the EWMA control chart.
sigma	true standard deviation.
df	actual degrees of freedom, corresponds to subgroup size (for known mean it is equal to the subgroup size, for unknown mean it is equal to subgroup size minus one).
s2.on	distinguishes between S^2 and S chart.
hs	so-called headstart (enables fast initial response); the default (NULL) yields the expected in-control value of S^2 (1) and S (c_4), respectively.
sided	distinguishes between one- and two-sided two-sided EWMA- S^2 control charts by choosing "upper" (upper chart without reflection at c1 – the actual value of c1 is not used), "Rupper" (upper chart with reflection at c1), "Rlower" (lower chart with reflection at cu), and "two" (two-sided chart), respectively.
r	dimension of the resulting linear equation system (highest order of the collocation polynomials).
qm	number of quadrature nodes for calculating the collocation definite integrals.

Details

sewma.arl determines the Average Run Length (ARL) by numerically solving the related ARL integral equation by means of collocation (Chebyshev polynomials).

Value

Returns a single value which resembles the ARL.

Author(s)

Sven Knoth

References

S. Knoth (2005), Accurate ARL computation for EWMA- S^2 control charts, *Statistics and Computing* 15, 341-352.

S. Knoth (2006), Computation of the ARL for CUSUM- S^2 schemes, *Computational Statistics & Data Analysis* 51, 499-512.

See Also

xewma.arl for zero-state ARL computation of EWMA control charts for monitoring normal mean.

Examples

```
## Knoth (2005)
## compare with Table 1 (p. 347): 249.9997
## Monte Carlo with 10^9 replicates: 249.9892 +/- 0.008
l <- .025
df <- 1
cu <- 1 + 1.661865*sqrt(1/(2-1))*sqrt(2/df)
sewma.arl(1,0,cu,1,df)

## ARL values for upper and lower EWMA charts with reflecting barriers
## (reflection at in-control level sigma0 = 1)
## examples from Knoth (2006), Tables 4 and 5

Ssewma.arl <- Vectorize("sewma.arl", "sigma")

## upper chart with reflection at sigma0=1 in Table 4
## original entries are
# sigma  ARL
# 1      100.0
# 1.01   85.3
# 1.02   73.4
# 1.03   63.5
# 1.04   55.4
# 1.05   48.7
# 1.1    27.9
# 1.2    12.9
# 1.3    7.86
# 1.4    5.57
# 1.5    4.30
# 2      2.11

## Not run:
```

```

l <- 0.15
df <- 4
cu <- 1 + 2.4831*sqrt(1/(2-1))*sqrt(2/df)
sigmas <- c(1 + (0:5)/100, 1 + (1:5)/10, 2)
arls <- round(Ssewma.arl(l, 1, cu, sigmas, df, sided="Rupper", r=100), digits=2)
data.frame(sigmas, arls)
## End(Not run)

## lower chart with reflection at sigma0=1 in Table 5
## original entries are
# sigma  ARL
# 1      200.04
# 0.9    38.47
# 0.8    14.63
# 0.7     8.65
# 0.6     6.31

## Not run:
l <- 0.115
df <- 5
cl <- 1 - 2.0613*sqrt(1/(2-1))*sqrt(2/df)
sigmas <- c((10:6)/10)
arls <- round(Ssewma.arl(l, cl, 1, sigmas, df, sided="Rlower", r=100), digits=2)
data.frame(sigmas, arls)
## End(Not run)

```

sewma.arl.prerun

Compute ARLs of EWMA control charts (variance charts) in case of estimated parameters

Description

Computation of the (zero-state) Average Run Length (ARL) for EWMA control charts (based on the sample variance S^2) monitoring normal variance with estimated parameters.

Usage

```
sewma.arl.prerun(l, cl, cu, sigma, df1, df2, hs=1, sided="upper",
r=40, qm=30, qm.sigma=30, truncate=1e-10)
```

Arguments

l	smoothing parameter lambda of the EWMA control chart.
cl	lower control limit of the EWMA control chart.
cu	upper control limit of the EWMA control chart.
sigma	true standard deviation.
df1	actual degrees of freedom, corresponds to subgroup size (for known mean it is equal to the subgroup size, for unknown mean it is equal to subgroup size minus one).

df2	degrees of freedom of the pre-run variance estimator.
hs	so-called headstart (enables fast initial response).
sided	distinguishes between one- and two-sided two-sided EWMA- S^2 control charts by choosing "upper" (upper chart without reflection at c_l – the actual value of c_l is not used), "Rupper" (upper chart with reflection at c_l), "Rlower" (lower chart with reflection at c_u), and "two" (two-sided chart), respectively.
r	dimension of the resulting linear equation system (highest order of the collocation polynomials).
qm	number of quadrature nodes for calculating the collocation definite integrals.
qm.sigma	number of quadrature nodes for convoluting the standard deviation uncertainty.
truncate	size of truncated tail.

Details

Essentially, the ARL function `sewma.arl` is convoluted with the distribution of the sample standard deviation. For details see Jones/Champ/Rigdon (2001) and Knoth (2014?).

Value

Returns a single value which resembles the ARL.

Author(s)

Sven Knoth

References

L. A. Jones, C. W. Champ, S. E. Rigdon (2001), The performance of exponentially weighted moving average charts with estimated parameters, *Technometrics* 43, 156-167.

S. Knoth (2005), Accurate ARL computation for EWMA- S^2 control charts, *Statistics and Computing* 15, 341-352.

S. Knoth (2006), Computation of the ARL for CUSUM- S^2 schemes, *Computational Statistics & Data Analysis* 51, 499-512.

See Also

`sewma.arl` for zero-state ARL function of EWMA control charts w/o pre run uncertainty.

Examples

```
## Knoth (2014?)
```

sewma.crit *Compute critical values of EWMA control charts (variance charts)*

Description

Computation of the critical values (similar to alarm limits) for different types of EWMA control charts (based on the sample variance S^2) monitoring normal variance.

Usage

```
sewma.crit(l,L0,df,sigma0=1,c1=NULL,cu=NULL,hs=NULL,s2.on=TRUE,
sided="upper",mode="fixed",ur=4,r=40,qm=30)
```

Arguments

l	smoothing parameter lambda of the EWMA control chart.
L0	in-control ARL.
df	actual degrees of freedom, corresponds to subgroup size (for known mean it is equal to the subgroup size, for unknown mean it is equal to subgroup size minus one).
sigma0	in-control standard deviation.
c1	deployed for sided="Rupper", that is, upper variance control chart with lower reflecting barrier c1.
cu	for two-sided (sided="two") and fixed upper control limit (mode="fixed") a value larger than sigma0 has to be given, for all other cases cu is ignored.
hs	so-called headstart (enables fast initial response); the default (NULL) yields the expected in-control value of S^2 (1) and S (c_4), respectively.
s2.on	distinguishes between S^2 and S chart.
sided	distinguishes between one- and two-sided two-sided EWMA- S^2 control charts by choosing "upper" (upper chart without reflection at c1 – the actual value of c1 is not used), "Rupper" (upper chart with reflection at c1), "Rlower" (lower chart with reflection at cu), and "two" (two-sided chart), respectively.
mode	only deployed for sided="two" – with "fixed" an upper control limit (see cu) is set and only the lower is calculated to obtain the in-control ARL L0, while with "unbiased" a certain unbiasedness of the ARL function is guaranteed (here, both the lower and the upper control limit are calculated). With "vanilla" limits symmetric around 1 (the in-control value of the variance) are determined, while for "eq. tails" the in-control ARL values of two single EWMA variance charts (decompose the two-sided scheme into one lower and one upper scheme) are matched.
ur	truncation of lower chart for eq. tails mode.
r	dimension of the resulting linear equation system (highest order of the collocation polynomials).
qm	number of quadrature nodes for calculating the collocation definite integrals.

Details

sewma.crit determines the critical values (similar to alarm limits) for given in-control ARL L_0 by applying secant rule and using sewma.arl(). In case of sided="two" and mode="unbiased" a two-dimensional secant rule is applied that also ensures that the maximum of the ARL function for given standard deviation is attained at σ_0 . See Knoth (2010) and the related example.

Value

Returns the lower and upper control limit c1 and cu.

Author(s)

Sven Knoth

References

- H.-J. Mittag and D. Stemann and B. Tewes (1998), EWMA-Karten zur "Überwachung der Streuung von Qualitätsmerkmalen, *Allgemeines Statistisches Archiv* 82, 327-338,
- C. A. Acosta-Mejía and J. J. Pignatiello Jr. and B. V. Rao (1999), A comparison of control charting procedures for monitoring process dispersion, *IIE Transactions* 31, 569-579.
- S. Knoth (2005), Accurate ARL computation for EWMA- S^2 control charts, *Statistics and Computing* 15, 341-352.
- S. Knoth (2006a), Computation of the ARL for CUSUM- S^2 schemes, *Computational Statistics & Data Analysis* 51, 499-512.
- S. Knoth (2006b), The art of evaluating monitoring schemes – how to measure the performance of control charts? in *Frontiers in Statistical Quality Control* 8, H.-J. Lenz and P.-T. Wilrich (Eds.), Physica Verlag, Heidelberg, Germany, 74-99.
- S. Knoth (2010), Control Charting Normal Variance – Reflections, Curiosities, and Recommendations, in *Frontiers in Statistical Quality Control* 9, H.-J. Lenz and P.-T. Wilrich (Eds.), Physica Verlag, Heidelberg, Germany, 3-18.

See Also

sewma.arl for calculation of ARL of variance charts.

Examples

```
## Mittag et al. (1998)
## compare their upper critical value 2.91 that
## leads to the upper control limit via the formula shown below
## (for the usual upper EWMA  $\sqrt{S^2}\sqrt{S^2}$ ).
## See Knoth (2006b) for a discussion of this EWMA setup and it's evaluation.

l <- 0.18
L0 <- 250
df <- 4
limits <- sewma.crit(l, L0, df)
limits["cu"]
```

```

limits.cu.mittag_et_al <- 1 + sqrt(1/(2-1))*sqrt(2/df)*2.91
limits.cu.mittag_et_al

## Knoth (2005)
## reproduce the critical value given in Figure 2 (c=1.661865) for
## upper EWMA  $\{S^2\}$  with df=1

l <- 0.025
L0 <- 250
df <- 1
limits <- sewma.crit(l, L0, df)
cv.Fig2 <- (limits["cu"]-1)/( sqrt(1/(2-1))*sqrt(2/df) )
cv.Fig2

## the small difference (sixth digit after decimal point) stems from
## tighter criterion in the secant rule implemented in the R package.

## demo of unbiased ARL curves
## Deploy, please, not matrix dimensions smaller than 50 -- for the
## sake of accuracy, the value 80 was used.
## Additionally, this example needs between 1 and 2 minutes on a 1.6 Ghz box.

## Not run:
l <- 0.1
L0 <- 500
df <- 4
limits <- sewma.crit(l, L0, df, sided="two", mode="unbiased", r=80)
SEWMA.arl <- Vectorize(sewma.arl, "sigma")
SEWMA.ARL <- function(sigma)
  SEWMA.arl(l, limits[1], limits[2], sigma, df, sided="two", r=80)
layout(matrix(1:2, nrow=1))
curve(SEWMA.ARL, .75, 1.25, log="y")
curve(SEWMA.ARL, .95, 1.05, log="y")
## End(Not run)
# the above stuff needs about 1 minute

## control limits for upper and lower EWMA charts with reflecting barriers
## (reflection at in-control level  $\sigma_0 = 1$ )
## examples from Knoth (2006a), Tables 4 and 5

## Not run:
## upper chart with reflection at  $\sigma_0=1$  in Table 4: c = 2.4831
l <- 0.15
L0 <- 100
df <- 4
limits <- sewma.crit(l, L0, df, c1=1, sided="Rupper", r=100)
cv.Tab4 <- (limits["cu"]-1)/( sqrt(1/(2-1))*sqrt(2/df) )
cv.Tab4

## lower chart with reflection at  $\sigma_0=1$  in Table 5: c = 2.0613
l <- 0.115
L0 <- 200

```

```
df <- 5
limits <- sewma.crit(l, L0, df, cu=1, sided="Rlower", r=100)
cv.Tab5 <- -(limits["c1"]-1)/( sqrt(1/(2-1))*sqrt(2/df) )
cv.Tab5
## End(Not run)
```

sewma.crit.prerun	<i>Compute critical values of EWMA (variance charts) control charts under pre-run uncertainty</i>
-------------------	---

Description

Computation of quantiles of the Run Length (RL) for EWMA control charts monitoring normal variance.

Usage

```
sewma.crit.prerun(l,L0,df1,df2,sigma0=1,c1=NULL,cu=NULL,hs=1,sided="upper",
mode="fixed",r=40,qm=30,qm.sigma=30,truncate=1e-10,
tail_approx=TRUE,c.error=1e-10,a.error=1e-9)
```

Arguments

l	smoothing parameter lambda of the EWMA control chart.
L0	in-control quantile value.
df1	actual degrees of freedom, corresponds to subgroup size (for known mean it is equal to the subgroup size, for unknown mean it is equal to subgroup size minus one).
df2	degrees of freedom of the pre-run variance estimator.
sigma,sigma0	true and in-control standard deviation, respectively.
c1	deployed for sided="Rupper", that is, upper variance control chart with lower reflecting barrier c1.
cu	for two-sided (sided="two") and fixed upper control limit (mode="fixed") a value larger than sigma0 has to be given, for all other cases cu is ignored.
hs	so-called headstart (enables fast initial response).
sided	distinguishes between one- and two-sided two-sided EWMA- S^2 control charts by choosing "upper" (upper chart without reflection at c1 – the actual value of c1 is not used), "Rupper" (upper chart with reflection at c1), "Rlower" (lower chart with reflection at cu),and "two" (two-sided chart), respectively.
mode	only deployed for sided="two" – with "fixed" an upper control limit (see cu) is set and only the lower is calculated to obtain the in-control ARL L0, while with "unbiased" a certain unbiasedness of the ARL function is guaranteed (here, both the lower and the upper control limit are calculated).
r	dimension of the resulting linear equation system (highest order of the collocation polynomials).

qm	number of quadrature nodes for calculating the collocation definite integrals.
qm.sigma	number of quadrature nodes for convoluting the standard deviation uncertainty.
truncate	size of truncated tail.
tail_approx	controls whether the geometric tail approximation is used (is faster) or not.
c.error	error bound for two succeeding values of the critical value during applying the secant rule.
a.error	error bound for the quantile level alpha during applying the secant rule.

Details

sewma.crit.prerun determines the critical values (similar to alarm limits) for given in-control ARL L_0 by applying secant rule and using `sewma.ar1.prerun()`. In case of `sided="two"` and `mode="unbiased"` a two-dimensional secant rule is applied that also ensures that the maximum of the ARL function for given standard deviation is attained at σ_0 . See Knoth (2010) for some details of the algorithm involved.

Value

Returns the lower and upper control limit `c1` and `cu`.

Author(s)

Sven Knoth

References

H.-J. Mittag and D. Stemann and B. Tewes (1998), EWMA-Karten zur "Überwachung der Streuung von Qualitätsmerkmalen", *Allgemeines Statistisches Archiv* 82, 327-338, S. Knoth (2005), Accurate ARL computation for EWMA- S^2 control charts, *Statistics and Computing* 15, 341-352.

S. Knoth (2010), Control Charting Normal Variance – Reflections, Curiosities, and Recommendations, in *Frontiers in Statistical Quality Control 9*, H.-J. Lenz and P.-T. Wilrich (Eds.), Physica Verlag, Heidelberg, Germany, 3-18.

See Also

`sewma.ar1.prerun` for calculation of ARL of variance charts under pre-run uncertainty and `sewma.crit` for the algorithm w/o pre-run uncertainty.

Examples

```
## Knoth (2014?)
```

sewma.q

*Compute RL quantiles of EWMA (variance charts) control charts***Description**

Computation of quantiles of the Run Length (RL) for EWMA control charts monitoring normal variance.

Usage

```
sewma.q(l, cl, cu, sigma, df, alpha, hs=1, sided="upper", r=40, qm=30)
```

```
sewma.q.crit(l,L0,alpha,df,sigma0=1,cl=NULL,cu=NULL,hs=1,sided="upper",
mode="fixed",ur=4,r=40,qm=30,c.error=1e-12,a.error=1e-9)
```

Arguments

l	smoothing parameter lambda of the EWMA control chart.
cl	deployed for sided="Rupper", that is, upper variance control chart with lower reflecting barrier cl.
cu	for two-sided (sided="two") and fixed upper control limit (mode="fixed") a value larger than sigma0 has to been given, for all other cases cu is ignored.
sigma,sigma0	true and in-control standard deviation, respectively.
df	actual degrees of freedom, corresponds to subgroup size (for known mean it is equal to the subgroup size, for unknown mean it is equal to subgroup size minus one).
alpha	quantile level.
hs	so-called headstart (enables fast initial response).
sided	distinguishes between one- and two-sided two-sided EWMA- S^2 control charts by choosing "upper" (upper chart without reflection at cl – the actual value of cl is not used), "Rupper" (upper chart with reflection at cl), "Rlower" (lower chart with reflection at cu),and "two" (two-sided chart), respectively.
mode	only deployed for sided="two" – with "fixed" an upper control limit (see cu) is set and only the lower is calculated to obtain the in-control ARL L0, while with "unbiased" a certain unbiasedness of the ARL function is guaranteed (here, both the lower and the upper control limit are calculated).
ur	truncation of lower chart for classic mode.
r	dimension of the resulting linear equation system (highest order of the collocation polynomials).
qm	number of quadrature nodes for calculating the collocation definite integrals.
L0	in-control quantile value.
c.error	error bound for two succeeding values of the critical value during applying the secant rule.
a.error	error bound for the quantile level alpha during applying the secant rule.

Details

Instead of the popular ARL (Average Run Length) quantiles of the EWMA stopping time (Run Length) are determined. The algorithm is based on Waldmann's survival function iteration procedure. Thereby the ideas presented in Knoth (2007) are used. `sewma.q.crit` determines the critical values (similar to alarm limits) for given in-control RL quantile L_0 at level α by applying secant rule and using `sewma.sf()`. In case of `sided="two"` and `mode="unbiased"` a two-dimensional secant rule is applied that also ensures that the minimum of the cdf for given standard deviation is attained at σ_0 .

Value

Returns a single value which resembles the RL quantile of order α and the lower and upper control limit `cl` and `cu`, respectively.

Author(s)

Sven Knoth

References

- H.-J. Mittag and D. Stemann and B. Tewes (1998), EWMA-Karten zur "Überwachung der Streuung von Qualitätsmerkmalen", *Allgemeines Statistisches Archiv* 82, 327-338,
- C. A. Acosta-Mejía and J. J. Pignatiello Jr. and B. V. Rao (1999), A comparison of control charting procedures for monitoring process dispersion, *IIE Transactions* 31, 569-579.
- S. Knoth (2005), Accurate ARL computation for EWMA- S^2 control charts, *Statistics and Computing* 15, 341-352.
- S. Knoth (2007), Accurate ARL calculation for EWMA control charts monitoring simultaneously normal mean and variance, *Sequential Analysis* 26, 251-264.
- S. Knoth (2010), Control Charting Normal Variance – Reflections, Curiosities, and Recommendations, in *Frontiers in Statistical Quality Control* 9, H.-J. Lenz and P.-T. Wilrich (Eds.), Physica Verlag, Heidelberg, Germany, 3-18.
- K.-H. Waldmann (1986), Bounds for the distribution of the run length of geometric moving average charts, *Appl. Statist.* 35, 151-158.

See Also

`sewma.arl` for calculation of ARL of variance charts and `sewma.sf` for the RL survival function.

Examples

```
## Knoth (2014?)
```

sewma.q.prerun	<i>Compute RL quantiles of EWMA (variance charts) control charts under pre-run uncertainty</i>
----------------	--

Description

Computation of quantiles of the Run Length (RL) for EWMA control charts monitoring normal variance.

Usage

```
sewma.q.prerun(l,cl,cu,sigma,df1,df2,alpha,hs=1,sided="upper",
r=40,qm=30,qm.sigma=30,truncate=1e-10)
```

```
sewma.q.crit.prerun(l,L0,alpha,df1,df2,sigma0=1,cl=NULL,cu=NULL,hs=1,
sided="upper",mode="fixed",r=40,qm=30,qm.sigma=30,truncate=1e-10,
tail_approx=TRUE,c.error=1e-10,a.error=1e-9)
```

Arguments

l	smoothing parameter lambda of the EWMA control chart.
cl	deployed for sided="Rupper", that is, upper variance control chart with lower reflecting barrier cl.
cu	for two-sided (sided="two") and fixed upper control limit (mode="fixed") a value larger than sigma0 has to been given, for all other cases cu is ignored.
sigma,sigma0	true and in-control standard deviation, respectively.
L0	in-control quantile value.
alpha	quantile level.
df1	actual degrees of freedom, corresponds to subgroup size (for known mean it is equal to the subgroup size, for unknown mean it is equal to subgroup size minus one).
df2	degrees of freedom of the pre-run variance estimator.
hs	so-called headstart (enables fast initial response).
sided	distinguishes between one- and two-sided two-sided EWMA- S^2 control charts by choosing "upper" (upper chart without reflection at cl – the actual value of cl is not used), "Rupper" (upper chart with reflection at cl), "Rlower" (lower chart with reflection at cu), and "two" (two-sided chart), respectively.
mode	only deployed for sided="two" – with "fixed" an upper control limit (see cu) is set and only the lower is calculated to obtain the in-control ARL L0, while with "unbiased" a certain unbiasedness of the ARL function is guaranteed (here, both the lower and the upper control limit are calculated).
r	dimension of the resulting linear equation system (highest order of the collocation polynomials).

qm	number of quadrature nodes for calculating the collocation definite integrals.
qm.sigma	number of quadrature nodes for convoluting the standard deviation uncertainty.
truncate	size of truncated tail.
tail_approx	controls whether the geometric tail approximation is used (is faster) or not.
c.error	error bound for two succeeding values of the critical value during applying the secant rule.
a.error	error bound for the quantile level alpha during applying the secant rule.

Details

Instead of the popular ARL (Average Run Length) quantiles of the EWMA stopping time (Run Length) are determined. The algorithm is based on Waldmann's survival function iteration procedure. Thereby the ideas presented in Knoth (2007) are used. `sewma.q.crit.prerun` determines the critical values (similar to alarm limits) for given in-control RL quantile L_0 at level alpha by applying secant rule and using `sewma.sf()`. In case of `sided="two"` and `mode="unbiased"` a two-dimensional secant rule is applied that also ensures that the minimum of the cdf for given standard deviation is attained at σ_0 .

Value

Returns a single value which resembles the RL quantile of order alpha and the lower and upper control limit `cl` and `cu`, respectively.

Author(s)

Sven Knoth

References

S. Knoth (2007), Accurate ARL calculation for EWMA control charts monitoring simultaneously normal mean and variance, *Sequential Analysis* 26, 251-264.

K.-H. Waldmann (1986), Bounds for the distribution of the run length of geometric moving average charts, *Appl. Statist.* 35, 151-158.

See Also

`sewma.q` and `sewma.q.crit` for the version w/o pre-run uncertainty.

Examples

```
## Knoth (2014?)
```

sewma.sf

*Compute the survival function of EWMA run length***Description**

Computation of the survival function of the Run Length (RL) for EWMA control charts monitoring normal variance.

Usage

```
sewma.sf(n, l, cl, cu, sigma, df, hs=1, sided="upper", r=40, qm=30)
```

Arguments

n	calculate sf up to value n.
l	smoothing parameter lambda of the EWMA control chart.
cl	lower control limit of the EWMA control chart.
cu	upper control limit of the EWMA control chart.
sigma	true standard deviation.
df	actual degrees of freedom, corresponds to subgroup size (for known mean it is equal to the subgroup size, for unknown mean it is equal to subgroup size minus one).
hs	so-called headstart (enables fast initial response).
sided	distinguishes between one- and two-sided two-sided EWMA- S^2 control charts by choosing "upper" (upper chart without reflection at cl – the actual value of cl is not used), "Rupper" (upper chart with reflection at cl), "Rlower" (lower chart with reflection at cu), and "two" (two-sided chart), respectively.
r	dimension of the resulting linear equation system (highest order of the collocation polynomials).
qm	number of quadrature nodes for calculating the collocation definite integrals.

Details

The survival function $P(L>n)$ and derived from it also the cdf $P(L\leq n)$ and the pmf $P(L=n)$ illustrate the distribution of the EWMA run length. For large n the geometric tail could be exploited. That is, with reasonable large n the complete distribution is characterized. The algorithm is based on Waldmann's survival function iteration procedure and on results in Knoth (2007).

Value

Returns a vector which resembles the survival function up to a certain point.

Author(s)

Sven Knoth

References

S. Knoth (2007), Accurate ARL calculation for EWMA control charts monitoring simultaneously normal mean and variance, *Sequential Analysis* 26, 251-264.

K.-H. Waldmann (1986), Bounds for the distribution of the run length of geometric moving average charts, *Appl. Statist.* 35, 151-158.

See Also

sewma.ar1 for zero-state ARL computation of variance EWMA control charts.

Examples

```
## Knoth (2014?)
```

```
sewma.sf.prerun          Compute the survival function of EWMA run length
```

Description

Computation of the survival function of the Run Length (RL) for EWMA control charts monitoring normal variance.

Usage

```
sewma.sf.prerun(n, l, cl, cu, sigma, df1, df2, hs=1, sided="upper",
qm=30, qm.sigma=30, truncate=1e-10, tail_approx=TRUE)
```

Arguments

n	calculate sf up to value n.
l	smoothing parameter lambda of the EWMA control chart.
cl	lower control limit of the EWMA control chart.
cu	upper control limit of the EWMA control chart.
sigma	true standard deviation.
df1	actual degrees of freedom, corresponds to subgroup size (for known mean it is equal to the subgroup size, for unknown mean it is equal to subgroup size minus one).
df2	degrees of freedom of the pre-run variance estimator.
hs	so-called headstart (enables fast initial response).
sided	distinguishes between one- and two-sided two-sided EWMA- S^2 control charts by choosing "upper" (upper chart without reflection at cl – the actual value of cl is not used), "Rupper" (upper chart with reflection at cl), "Rlower" (lower chart with reflection at cu), and "two" (two-sided chart), respectively.
qm	number of quadrature nodes for calculating the collocation definite integrals.

qm.sigma number of quadrature nodes for convoluting the standard deviation uncertainty.
 truncate size of truncated tail.
 tail_approx Controls whether the geometric tail approximation is used (is faster) or not.

Details

The survival function $P(L>n)$ and derived from it also the cdf $P(L\leq n)$ and the pmf $P(L=n)$ illustrate the distribution of the EWMA run length. For large n the geometric tail could be exploited. That is, with reasonable large n the complete distribution is characterized. The algorithm is based on Waldmann's survival function iteration procedure and on results in Knoth (2007)...

Value

Returns a vector which resembles the survival function up to a certain point.

Author(s)

Sven Knoth

References

S. Knoth (2007), Accurate ARL calculation for EWMA control charts monitoring simultaneously normal mean and variance, *Sequential Analysis* 26, 251-264.

K.-H. Waldmann (1986), Bounds for the distribution of the run length of geometric moving average charts, *Appl. Statist.* 35, 151-158.

See Also

sewma.sf for the RL survival function of EWMA control charts w/o pre-run uncertainty.

Examples

```
## Knoth (2014?)
```

tol.lim.fac *Two-sided tolerance limit factors*

Description

For constructing tolerance intervals, which cover a given proportion p of a normal distribution with unknown mean and variance with confidence $1 - \alpha$, one needs to calculate the so-called tolerance limit factors k . These values are computed for a given sample size n .

Usage

```
tol.lim.fac(n,p,a,mode="WW",m=30)
```


Arguments

n	sample size.
p	coverage.
a	error probability α , resulting interval covers at least proportion p with confidence of at least $1 - \alpha$.
mode	distinguish between Wald/Wolfowitz' approximation method ("WW") and the more accurate approach ("exact") based on Gauss-Legendre quadrature.
m	number of abscissas for the quadrature (needed only for method="exact"), of course, the larger the more accurate.

Details

tol.lim.fac determines tolerance limits factors k by means of the fast and simple approximation due to Wald/Wolfowitz (1946) and of Gauss-Legendre quadrature like Odeh/Owen (1980), respectively, who used in fact the Simpson Rule. Then, by $\bar{x} \pm k \cdot s$ one can build the tolerance intervals which cover at least proportion p of a normal distribution for given confidence level of $1 - \alpha$. \bar{x} and s stand for the sample mean and the sample standard deviation, respectively.

Value

Returns a single value which resembles the tolerance limit factor.

Author(s)

Sven Knoth

References

- A. Wald, J. Wolfowitz (1946), Tolerance limits for a normal distribution, *Annals of Mathematical Statistics* 17, 208-215.
- R. E. Odeh, D. B. Owen (1980), *Tables for Normal Tolerance Limits, Sampling Plans, and Screening*, Marcel Dekker, New York.

See Also

qnorm for the "asymptotic" case – cf. second example.

Examples

```
n <- 2:10
p <- .95
a <- .05
kWW <- sapply(n,p=p,a=a,tol.lim.fac)
kEX <- sapply(n,p=p,a=a,mode="exact",tol.lim.fac)
print(cbind(n,kWW,kEX),digits=4)
## Odeh/Owen (1980), page 98, in Table 3.4.1
## n factor k
## 2 36.519
```

```
## 3 9.789
## 4 6.341
## 5 5.077
## 6 4.422
## 7 4.020
## 8 3.746
## 9 3.546
## 10 3.393

## n -> infty
n <- 10^{1:7}
p <- .95
a <- .05
kEX <- round(sapply(n,p=p,a=a,mode="exact",tol.lim.fac),digits=4)
kEXinf <- round(qnorm(1-a/2),digits=4)
print(rbind(cbind(n,kEX),c("infinity",kEXinf)),quote=FALSE)
```

x.res.ewma.arl

Compute ARLs of EWMA residual control charts

Description

Computation of the (zero-state) Average Run Length (ARL) for EWMA residual control charts monitoring normal mean, variance, or mean and variance simultaneously. Additionally, the probability of misleading signals (PMS) is calculated.

Usage

```
x.res.ewma.arl(l, c, mu, alpha=0, n=5, hs=0, r=40)

s.res.ewma.arl(l, cu, sigma, mu=0, alpha=0, n=5, hs=1, r=40, qm=30)

xs.res.ewma.arl(lx, cx, ls, csu, mu, sigma, alpha=0,
n=5, hsx=0, rx=40, hss=1, rs=40, qm=30)

xs.res.ewma.pms(lx, cx, ls, csu, mu, sigma, type="3",
alpha=0, n=5, hsx=0, rx=40, hss=1, rs=40, qm=30)
```

Arguments

l, lx, ls	smoothing parameter(s) lambda of the EWMA control chart.
c, cu, cx, csu	critical value (similar to alarm limit) of the EWMA control charts.
mu	true mean.
sigma	true standard deviation.
alpha	the AR(1) coefficient – first order autocorrelation of the original data.
n	batch size.
hs, hsx, hss	so-called headstart (enables fast initial response).

r, rx, rs	number of quadrature nodes or size of collocation base, dimension of the resulting linear equation system is equal to r (two-sided).
qm	number of nodes for collocation quadratures.
type	PMS type, for PMS="3" (the default) the probability of getting a mean signal despite the variance changed, and for PMS="4" the opposite case is dealt with.

Details

The above list of functions provides the application of algorithms developed for iid data to the residual case. To be more precise, the underlying model is a sequence of normally distributed batches with size n with autocorrelation within the batch and independence between the batches (see also the references below). It is restricted to the classical EWMA chart types, that is two-sided for the mean, upper charts for the variance, and all equipped with fixed limits. The autocorrelation is modeled by an AR(1) process with parameter alpha. Additionally, with `xs.res.ewma.pms` the probability of misleading signals (PMS) of type is calculated. This is offered exclusively in this small collection so that for iid data this function has to be used too (with `alpha=0`).

Value

Return single values which resemble the ARL and the PMS, respectively.

Author(s)

Sven Knoth

References

- S. Knoth, M. C. Morais, A. Pacheco, W. Schmid (2009), Misleading Signals in Simultaneous Residual Schemes for the Mean and Variance of a Stationary Process, *Commun. Stat., Theory Methods* 38, 2923-2943.
- S. Knoth, W. Schmid, A. Schoene (2001), Simultaneous Shewhart-Type Charts for the Mean and the Variance of a Time Series, *Frontiers of Statistical Quality Control 6*, A. Lenz, H.-J. & Wilrich, P.-T. (Eds.), 6, 61-79.
- S. Knoth, W. Schmid (2002) Monitoring the mean and the variance of a stationary process, *Statistica Neerlandica* 56, 77-100.

See Also

`xewma.arl`, `sewma.arl`, and `xsewma.arl` as more elaborated functions in the iid case.

Examples

```
## Not run:
## S. Knoth, W. Schmid (2002)

cat("\nFragments of Table 2 (n=5, lambda.1=lambda.2)\n")

lambdas <- c(.5, .25, .1, .05)
L0 <- 500
```

```

n <- 5

crit <- NULL
for ( lambda in lambdas ) {
  cs <- xsewma.crit(lambda, lambda, L0, n-1)
  x.e <- round(cs[1], digits=4)
  names(x.e) <- NULL
  s.e <- round((cs[3]-1) * sqrt((2-lambda)/lambda)*sqrt((n-1)/2), digits=4)
  names(s.e) <- NULL
  crit <- rbind(crit, data.frame(lambda, x.e, s.e))
}

## orinal values are (Markov chain approximation with 50 states)
# lambda x.e    s.e
# 0.50 3.2765 4.6439
# 0.25 3.2168 4.0149
# 0.10 3.0578 3.3376
# 0.05 2.8817 2.9103

print(crit)

cat("\nFragments of Table 4 (n=5, lambda.1=lambda.2=0.1)\n\n")

lambda <- .1
# the algorithm used in Knoth/Schmid is less accurate -- proceed with their values
cx <- x.e <- 3.0578
s.e <- 3.3376
csu <- 1 + s.e * sqrt(lambda/(2-lambda))*sqrt(2/(n-1))

alpha <- .3

a.values <- c((0:6)/4, 2)
d.values <- c(1 + (0:5)/10, 1.75 , 2)

arls <- NULL
for ( delta in d.values ) {
  row <- NULL
  for ( mu in a.values ) {
    arl <- round(xs.res.ewma.arl(lambda, cx, lambda, csu, mu*sqrt(n), delta, alpha=alpha, n=n),
                digits=2)
    names(arl) <- NULL
    row <- c(row, arl)
  }
  arls <- rbind(arls, data.frame(t(row)))
}
names(arls) <- a.values
rownames(arls) <- d.values

## orinal values are (now Monte-Carlo with 10^6 replicates)
#      0 0.25 0.5 0.75 1 1.25 1.5 2
#1    502.44 49.50 14.21 7.93 5.53 4.28 3.53 2.65

```

```

#1.1  73.19 32.91 13.33 7.82 5.52 4.29 3.54 2.66
#1.2  24.42 18.88 11.37 7.44 5.42 4.27 3.54 2.67
#1.3  13.11 11.83  9.09 6.74 5.18 4.17 3.50 2.66
#1.4   8.74  8.31  7.19 5.89 4.81 4.00 3.41 2.64
#1.5   6.50  6.31  5.80 5.08 4.37 3.76 3.28 2.59
#1.75  3.94  3.90  3.78 3.59 3.35 3.09 2.83 2.40
#2     2.85  2.84  2.80 2.73 2.63 2.51 2.39 2.14

print(arls)

## S. Knoth, M. C. Morais, A. Pacheco, W. Schmid (2009)

cat("\nFragments of Table 5 (n=5, lambda=0.1)\n\n")

d.values <- c(1.02, 1 + (1:5)/10, 1.75 , 2)

arl.x <- arl.s <- arl.xs <- PMS.3 <- NULL
for ( delta in d.values ) {
  arl.x <- c(arl.x, round(x.res.ewma.arl(lambda, cx/delta, 0, n=n),
                        digits=3))
  arl.s <- c(arl.s, round(s.res.ewma.arl(lambda, csu, delta, n=n),
                        digits=3))
  arl.xs <- c(arl.xs, round(xs.res.ewma.arl(lambda, cx, lambda, csu, 0, delta, n=n),
                        digits=3))
  PMS.3 <- c(PMS.3, round(xs.res.ewma.pms(lambda, cx, lambda, csu, 0, delta, n=n),
                        digits=6))
}

## orinal values are (Markov chain approximation)
# delta  arl.x  arl.s  arl.xs  PMS.3
#  1.02 833.086 518.935 323.324 0.381118
#  1.10 454.101  84.208  73.029 0.145005
#  1.20 250.665  25.871  24.432 0.071024
#  1.30 157.343  13.567  13.125 0.047193
#  1.40 108.112   8.941   8.734 0.035945
#  1.50  79.308   6.614   6.493 0.029499
#  1.75  44.128   3.995   3.942 0.021579
#  2.00  28.974   2.887   2.853 0.018220

print(cbind(delta=d.values, arl.x, arl.s, arl.xs, PMS.3))

cat("\nFragments of Table 6 (n=5, lambda=0.1)\n\n")

alphas <- c(-0.9, -0.5, -0.3, 0, 0.3, 0.5, 0.9)
deltas <- c(0.05, 0.25, 0.5, 0.75, 1, 1.25, 1.5, 2)

PMS.4 <- NULL
for ( ir in 1:length(deltas) ) {
  mu <- deltas[ir]*sqrt(n)
  pms <- NULL
  for ( alpha in alphas ) {

```

```

pms <- c(pms, round(xs.res.ewma.pms(lambda, cx, lambda, csu, mu, 1, type="4", alpha=alpha, n=n),
                    digits=6))
}
PMS.4 <- rbind(PMS.4, data.frame(delta=deltas[ir], t(pms)))
}
names(PMS.4) <- c("delta", alphas)
rownames(PMS.4) <- NULL

## orinal values are (Markov chain approximation)
# delta    -0.9    -0.5    -0.3     0     0.3     0.5     0.9
# 0.05 0.055789 0.224521 0.279842 0.342805 0.391299 0.418915 0.471386
# 0.25 0.003566 0.009522 0.014580 0.025786 0.044892 0.066584 0.192023
# 0.50 0.002994 0.001816 0.002596 0.004774 0.009259 0.015303 0.072945
# 0.75 0.006967 0.000703 0.000837 0.001529 0.003400 0.006424 0.046602
# 1.00 0.005098 0.000402 0.000370 0.000625 0.001589 0.003490 0.039978
# 1.25 0.000084 0.000266 0.000202 0.000300 0.000867 0.002220 0.039773
# 1.50 0.000000 0.000256 0.000120 0.000163 0.000531 0.001584 0.042734
# 2.00 0.000000 0.000311 0.000091 0.000056 0.000259 0.001029 0.054543

print(PMS.4)

## End(Not run)

```

xcusum.ad

Compute steady-state ARLs of CUSUM control charts

Description

Computation of the steady-state Average Run Length (ARL) for different types of CUSUM control charts monitoring normal mean.

Usage

```
xcusum.ad(k, h, mu1, mu0 = 0, sided = "one", r = 30)
```

Arguments

k	reference value of the CUSUM control chart.
h	decision interval (alarm limit, threshold) of the CUSUM control chart.
mu1	out-of-control mean.
mu0	in-control mean.
sided	distinguish between one-, two-sided and Crosier's modified two-sided CUSUM scheme by choosing "one", "two", and "Crosier", respectively.
r	number of quadrature nodes, dimension of the resulting linear equation system is equal to r+1 (one-, two-sided) or 2r+1 (Crosier).

Details

xcusum.ad determines the steady-state Average Run Length (ARL) by numerically solving the related ARL integral equation by means of the Nystroem method based on Gauss-Legendre quadrature and using the power method for deriving the largest in magnitude eigenvalue and the related left eigenfunction.

Value

Returns a single value which resembles the steady-state ARL.

Note

Be cautious in increasing the dimension parameter r for two-sided CUSUM schemes. The resulting matrix dimension is r^2 times r^2 . Thus, go beyond 30 only on fast machines. This is the only case, were the package routines are based on the Markov chain approach. Moreover, the two-sided CUSUM scheme needs a two-dimensional Markov chain.

Author(s)

Sven Knoth

References

R. B. Crosier (1986), A new two-sided cumulative quality control scheme, *Technometrics* 28, 187-194.

See Also

xcusum.ar1 for zero-state ARL computation and xewma.ad for the steady-state ARL of EWMA control charts.

Examples

```
## comparison of zero-state (= worst case ) and steady-state performance
## for one-sided CUSUM control charts

k <- .5
h <- xcusum.crit(k,500)
mu <- c(0,.5,1,1.5,2)
ar1 <- sapply(mu,k=k,h=h,xcusum.ar1)
ad <- sapply(mu,k=k,h=h,xcusum.ad)
round(cbind(mu,ar1,ad),digits=2)

## Crosier (1986), Crosier's modified two-sided CUSUM
## He introduced the modification and evaluated it by means of
## Markov chain approximation

k <- .5
h2 <- 4
hC <- 3.73
mu <- c(0,.25,.5,.75,1,1.5,2,2.5,3,4,5)
```

```
ad2 <- sapply(mu,k=k,h=h2,sided="two",r=20,xcusum.ad)
adC <- sapply(mu,k=k,h=hC,sided="Crosier",xcusum.ad)
round(cbind(mu,ad2,adC),digits=2)
```

```
## results in the original paper are (in Table 5)
## 0.00 163. 164.
## 0.25 71.6 69.0
## 0.50 25.2 24.3
## 0.75 12.3 12.1
## 1.00 7.68 7.69
## 1.50 4.31 4.39
## 2.00 3.03 3.12
## 2.50 2.38 2.46
## 3.00 2.00 2.07
## 4.00 1.55 1.60
## 5.00 1.22 1.29
```

xcusum.arl

Compute ARLs of CUSUM control charts

Description

Computation of the (zero-state) Average Run Length (ARL) for different types of CUSUM control charts monitoring normal mean.

Usage

```
xcusum.arl(k, h, mu, hs = 0, sided = "one", method = "igl", q = 1, r = 30)
```

Arguments

k	reference value of the CUSUM control chart.
h	decision interval (alarm limit, threshold) of the CUSUM control chart.
mu	true mean.
hs	so-called headstart (give fast initial response).
sided	distinguish between one-, two-sided and Crosier's modified two-sided CUSUM scheme by choosing "one", "two", and "Crosier", respectively.
method	deploy the integral equation ("igl") or Markov chain approximation ("mc") method to calculate the ARL (currently only for two-sided CUSUM implemented).
q	change point position. For $q = 1$ and $\mu = \mu_0$ and $\mu = \mu_1$, the usual zero-state ARLs for the in-control and out-of-control case, respectively, are calculated. For $q > 1$ and $\mu! = 0$ conditional delays, that is, $E_q(L - q + 1 L \geq q)$, will be determined. Note that $\mu_0=0$ is implicitly fixed.
r	number of quadrature nodes, dimension of the resulting linear equation system is equal to $r+1$ (one-, two-sided) or $2r+1$ (Crosier).

Details

xcusum.ar1 determines the Average Run Length (ARL) by numerically solving the related ARL integral equation by means of the Nystroem method based on Gauss-Legendre quadrature.

Value

Returns a vector of length q which resembles the ARL and the sequence of conditional expected delays for $q=1$ and $q>1$, respectively.

Author(s)

Sven Knoth

References

A. L. Goel, S. M. Wu (1971), Determination of A.R.L. and a contour nomogram for CUSUM charts to control normal mean, *Technometrics* 13, 221-230.

D. Brook, D. A. Evans (1972), An approach to the probability distribution of cusum run length, *Biometrika* 59, 539-548.

J. M. Lucas, R. B. Crosier (1982), Fast initial response for cusum quality-control schemes: Give your cusum a headstart, *Technometrics* 24, 199-205.

L. C. Vance (1986), Average run lengths of cumulative sum control charts for controlling normal means, *Journal of Quality Technology* 18, 189-193.

K.-H. Waldmann (1986), Bounds for the distribution of the run length of one-sided and two-sided CUSUM quality control schemes, *Technometrics* 28, 61-67.

R. B. Crosier (1986), A new two-sided cumulative quality control scheme, *Technometrics* 28, 187-194.

See Also

xewma.ar1 for zero-state ARL computation of EWMA control charts and xcusum.ad for the steady-state ARL.

Examples

```
## Brook/Evans (1972), one-sided CUSUM
## Their results are based on the less accurate Markov chain approach.

k <- .5
h <- 3
round(c( xcusum.ar1(k,h,0), xcusum.ar1(k,h,1.5) ),digits=2)

## results in the original paper are L0 = 117.59, L1 = 3.75 (in Subsection 4.3).

## Lucas, Crosier (1982)
## (one- and) two-sided CUSUM with possible headstarts

k <- .5
h <- 4
```

```

mu <- c(0,.25,.5,.75,1,1.5,2,2.5,3,4,5)
ar11 <- sapply(mu,k=k,h=h,sided="two",xcusum.ar1)
ar12 <- sapply(mu,k=k,h=h,hs=h/2,sided="two",xcusum.ar1)
round(cbind(mu,ar11,ar12),digits=2)

## results in the original paper are (in Table 1)
## 0.00 168. 149.
## 0.25 74.2 62.7
## 0.50 26.6 20.1
## 0.75 13.3 8.97
## 1.00 8.38 5.29
## 1.50 4.75 2.86
## 2.00 3.34 2.01
## 2.50 2.62 1.59
## 3.00 2.19 1.32
## 4.00 1.71 1.07
## 5.00 1.31 1.01.

## Vance (1986), one-sided CUSUM
## The first paper on using Nystroem method and Gauss-Legendre quadrature
## for solving the ARL integral equation (see as well Goel/Wu, 1971)

k <- 0
h <- 10
mu <- c(-.25,-.125,0,.125,.25,.5,.75,1)
round(cbind(mu,sapply(mu,k=k,h=h,xcusum.ar1)),digits=2)

## results in the original paper are (in Table 1 incl. Goel/Wu (1971) results)
## -0.25 2071.51
## -0.125 400.28
## 0.0 124.66
## 0.125 59.30
## 0.25 36.71
## 0.50 20.37
## 0.75 14.06
## 1.00 10.75.

## Waldmann (1986),
## one- and two-sided CUSUM

## one-sided case

k <- .5
h <- 3
mu <- c(-.5,0,.5)
round(sapply(mu,k=k,h=h,xcusum.ar1),digits=2)

## results in the original paper are 1963, 117.4, and 17.35, resp.
## (in Tables 3, 1, and 5, resp.).

## two-sided case

k <- .6

```

```

h <- 3
round(xcusum.arl(k,h,-.2,sided="two"),digits=1) # fits to Waldmann's setup

## result in the original paper is 65.4 (in Table 6).

## Crosier (1986), Crosier's modified two-sided CUSUM
## He introduced the modification and evaluated it by means of
## Markov chain approximation

k <- .5
h <- 3.73
mu <- c(0,.25,.5,.75,1,1.5,2,2.5,3,4,5)
round(cbind(mu,sapply(mu,k=k,h=h,sided="Crosier",xcusum.arl)),digits=2)

## results in the original paper are (in Table 3)
## 0.00 168.
## 0.25 70.7
## 0.50 25.1
## 0.75 12.5
## 1.00 7.92
## 1.50 4.49
## 2.00 3.17
## 2.50 2.49
## 3.00 2.09
## 4.00 1.60
## 5.00 1.22.

## SAS/QC manual 1999
## one- and two-sided CUSUM schemes

## one-sided

k <- .25
h <- 8
mu <- 2.5
print(xcusum.arl(k,h,mu),digits=12)
print(xcusum.arl(k,h,mu,hs=.1),digits=12)

## original results are 4.1500836225 and 4.1061588131.

## two-sided

print(xcusum.arl(k,h,mu,sided="two"),digits=12)

## original result is 4.1500826715.

```

Description

Computation of the decision intervals (alarm limits) for different types of CUSUM control charts monitoring normal mean.

Usage

```
xcusum.crit(k, L0, mu0 = 0, hs = 0, sided = "one", r = 30)
```

Arguments

k	reference value of the CUSUM control chart.
L0	in-control ARL.
mu0	in-control mean.
hs	so-called headstart (enables fast initial response).
sided	distinguishes between one-, two-sided and Crosier's modified two-sided CUSUM scheme by choosing "one", "two", and "Crosier", respectively.
r	number of quadrature nodes, dimension of the resulting linear equation system is equal to r+1 (one-, two-sided) or 2r+1 (Crosier).

Details

xcusum.crit determines the decision interval (alarm limit) for given in-control ARL L0 by applying secant rule and using xcusum.arl().

Value

Returns a single value which resembles the decision interval h.

Author(s)

Sven Knoth

See Also

xcusum.arl for zero-state ARL computation.

Examples

```
k <- .5
incontrolARL <- c(500,5000,50000)
sapply(incontrolARL,k=k,xcusum.crit,r=10) # accuracy with 10 nodes
sapply(incontrolARL,k=k,xcusum.crit,r=20) # accuracy with 20 nodes
sapply(incontrolARL,k=k,xcusum.crit)      # accuracy with 30 nodes
```

xcusum.crit.L0h	<i>Compute the CUSUM reference value k for given in-control ARL and threshold h</i>
-----------------	---

Description

Computation of the reference value k for one-sided CUSUM control charts monitoring normal mean, if the in-control ARL L_0 and the alarm threshold h are given.

Usage

```
xcusum.crit.L0h(L0, h, hs=0, sided="one", r=30, L0.eps=1e-6, k.eps=1e-8)
```

Arguments

L0	in-control ARL.
h	alarm level of the CUSUM control chart.
hs	so-called headstart (enables fast initial response).
sided	distinguishes between one-, two-sided and Crosier's modified two-sided CUSUM scheme choosing "one", "two", and "Crosier", respectively.
r	number of quadrature nodes, dimension of the resulting linear equation system is equal to r+1 (one-, two-sided) or 2r+1 (Crosier).
L0.eps	error bound for the L_0 error.
k.eps	bound for the difference of two successive values of k.

Details

xcusum.crit.L0h determines the reference value k for given in-control ARL L_0 and alarm level h by applying secant rule and using xcusum.arl(). Note that not for any combination of L_0 and h a solution exists – for given L_0 there is a maximal value for h to get a valid result k.

Value

Returns a single value which resembles the reference value k.

Author(s)

Sven Knoth

See Also

xcusum.arl for zero-state ARL computation.

Examples

```

L0 <- 100
h.max <- xcusum.crit(0, L0, 0)
hs <- (300:1)/100
hs <- hs[hs < h.max]
ks <- NULL
for ( h in hs ) ks <- c(ks, xcusum.crit.L0h(L0, h))
k.max <- qnorm( 1 - 1/L0 )
plot(hs, ks, type="l", ylim=c(0, max(k.max, ks)), xlab="h", ylab="k")
abline(h=c(0, k.max), col="red")

```

xcusum.crit.L0L1	<i>Compute the CUSUM k and h for given in-control ARL L0 and out-of-control L1</i>
------------------	--

Description

Computation of the reference value k and the alarm threshold h for one-sided CUSUM control charts monitoring normal mean, if the in-control ARL L0 and the out-of-control L1 are given.

Usage

```
xcusum.crit.L0L1(L0, L1, hs=0, sided="one", r=30, L1.eps=1e-6, k.eps=1e-8)
```

Arguments

L0	in-control ARL.
L1	out-of-control ARL.
hs	so-called headstart (enables fast initial response).
sided	distinguishes between one-, two-sided and Crosier's modified two-sided CUSUM schemoosing "one", "two", and "Crosier", respectively.
r	number of quadrature nodes, dimension of the resulting linear equation system is equal to r+1 (one-, two-sided) or 2r+1 (Crosier).
L1.eps	error bound for the L1 error.
k.eps	bound for the difference of two successive values of k.

Details

xcusum.crit.L0L1 determines the reference value k and the alarm threshold h for given in-control ARL L0 and out-of-control ARL L1 by applying secant rule and using xcusum.arl() and xcusum.crit(). These CUSUM design rules were firstly (and quite rarely afterwards) used by Ewan and Kemp.

Value

Returns two values which resemble the reference value k and the threshold h.

Author(s)

Sven Knoth

References

- W. D. Ewan and K. W. Kemp (1960), Sampling inspection of continuous processes with no auto-correlation between successive results, *Biometrika* 47, 363-380.
- K. W. Kemp (1962), The Use of Cumulative Sums for Sampling Inspection Schemes, *Journal of the Royal Statistical Society C, Applied Statistics*, 10, 16-31.

See Also

xcusum.ar1 for zero-state ARL and xcusum.crit for threshold h computation.

Examples

```
## Table 2 from Ewan/Kemp (1960) -- one-sided CUSUM
#
# A.R.L. at A.Q.L.   A.R.L. at A.Q.L.   k     h
#     1000           3           1.12  2.40
#     1000           7           0.65  4.06
#     500            3           1.04  2.26
#     500            7           0.60  3.80
#     250            3           0.94  2.11
#     250            7           0.54  3.51
#
L0.set <- c(1000, 500, 250)
L1.set <- c(3, 7)
cat("\nL0\tL1\tk\th\n")
for ( L0 in L0.set ) {
  for ( L1 in L1.set ) {
    result <- round(xcusum.crit.L0L1(L0, L1), digits=2)
    cat(paste(L0, L1, result[1], result[2], sep="\t"), "\n")
  }
}
#
# two confirmation runs
xcusum.ar1(0.54, 3.51, 0) # Ewan/Kemp
xcusum.ar1(result[1], result[2], 0) # here
xcusum.ar1(0.54, 3.51, 2*0.54) # Ewan/Kemp
xcusum.ar1(result[1], result[2], 2*result[1]) # here
#
## Table II from Kemp (1962) -- two-sided CUSUM
#
#   Lr           k
#   La=250   La=500   La=1000
#   2.5       1.05    1.17    1.27
#   3.0       0.94    1.035   1.13
#   4.0       0.78    0.85    0.92
#   5.0       0.68    0.74    0.80
#   6.0       0.60    0.655   0.71
```

```

# 7.5      0.52   0.57   0.62
# 10.0     0.43   0.48   0.52
#
L0.set <- c(250, 500, 1000)
L1.set <- c(2.5, 3:6, 7.5, 10)
cat("\nL1\tL0=250\tL0=500\tL0=1000\n")
for ( L1 in L1.set ) {
  cat(L1)
  for ( L0 in L0.set ) {
    result <- round(xcusum.crit.L0L1(L0, L1, sided="two"), digits=2)
    cat("\t", result[1])
  }
  cat("\n")
}

```

xcusum.q

Compute RL quantiles of CUSUM control charts

Description

Computation of quantiles of the Run Length (RL) for CUSUM control charts monitoring normal mean.

Usage

```
xcusum.q(k, h, mu, alpha, hs=0, sided="one", r=40)
```

Arguments

k	reference value of the CUSUM control chart.
h	decision interval (alarm limit, threshold) of the CUSUM control chart.
mu	true mean.
alpha	quantile level.
hs	so-called headstart (enables fast initial response).
sided	distinguishes between one- and two-sided CUSUM control chart by choosing "one" and "two", respectively.
r	number of quadrature nodes, dimension of the resulting linear equation system is equal to r+1.

Details

Instead of the popular ARL (Average Run Length) quantiles of the CUSUM stopping time (Run Length) are determined. The algorithm is based on Waldmann's survival function iteration procedure.

Value

Returns a single value which resembles the RL quantile of order q.

Author(s)

Sven Knoth

References

K.-H. Waldmann (1986), Bounds for the distribution of the run length of one-sided and two-sided CUSUM quality control schemes, *Technometrics* 28, 61-67.

See Also

xcusum.arl for zero-state ARL computation of CUSUM control charts.

Examples

```
## Waldmann (1986), one-sided CUSUM, Table 2
## original values are 345, 82, 9

XCUSUM.Q <- Vectorize("xcusum.q", "alpha")
k <- .5
h <- 3
mu <- 0 # corresponds to Waldmann's -0.5
a.list <- c(.95, .5, .05)
rl.quantiles <- ceiling(XCUSUM.Q(k, h, mu, a.list))
cbind(a.list, rl.quantiles)
```

xcusum.sf

*Compute the survival function of CUSUM run length***Description**

Computation of the survival function of the Run Length (RL) for CUSUM control charts monitoring normal mean.

Usage

```
xcusum.sf(k, h, mu, n, hs=0, sided="one", r=40)
```

Arguments

k	reference value of the CUSUM control chart.
h	decision interval (alarm limit, threshold) of the CUSUM control chart.
mu	true mean.
n	calculate sf up to value n.
hs	so-called headstart (enables fast initial response).
sided	distinguishes between one- and two-sided CUSUM control chart by choosing "one" and "two", respectively.
r	number of quadrature nodes, dimension of the resulting linear equation system is equal to r+1.

Details

The survival function $P(L > n)$ and derived from it also the cdf $P(L \leq n)$ and the pmf $P(L = n)$ illustrate the distribution of the CUSUM run length. For large n the geometric tail could be exploited. That is, with reasonable large n the complete distribution is characterized. The algorithm is based on Waldmann's survival function iteration procedure.

Value

Returns a vector which resembles the survival function up to a certain point.

Author(s)

Sven Knoth

References

K.-H. Waldmann (1986), Bounds for the distribution of the run length of one-sided and two-sided CUSUM quality control schemes, *Technometrics* 28, 61-67.

See Also

xcusum.q for computation of CUSUM run length quantiles.

Examples

```
## Waldmann (1986), one-sided CUSUM, Table 2

k <- .5
h <- 3
mu <- 0 # corresponds to Waldmann's -0.5
SF <- xcusum.sf(k, h, 0, 1000)
plot(1:length(SF), SF, type="l", xlab="n", ylab="P(L>n)", ylim=c(0,1))
#
```

xDcusum.arl

Compute ARLs of CUSUM control charts under drift

Description

Computation of the (zero-state and other) Average Run Length (ARL) under drift for one-sided CUSUM control charts monitoring normal mean.

Usage

```
xDcusum.arl(k, h, delta, hs = 0, sided = "one",
mode = "Gan", m = NULL, q = 1, r = 30, with0 = FALSE)
```

Arguments

k	reference value of the CUSUM control chart.
h	decision interval (alarm limit, threshold) of the CUSUM control chart.
delta	true drift parameter.
hs	so-called headstart (enables fast initial response).
sided	distinguishes between one- and two-sided CUSUM control chart by choosing "one" and "two", respectively. Currently, the two-sided scheme is not implemented.
mode	decide whether Gan's or Knoth's approach is used. Use "Gan" and "Knoth", respectively.
m	parameter used if mode="Gan". m is design parameter of Gan's approach. If m=NULL, then m will increased until the resulting ARL does not change anymore.
q	change point position. For $q = 1$ and $\mu = \mu_0$ and $\mu = \mu_1$, the usual zero-state ARLs for the in-control and out-of-control case, respectively, are calculated. For $q > 1$ and $\mu \neq 0$ conditional delays, that is, $E_q(L - q + 1 L \geq q)$, will be determined. Note that $\mu_0=0$ is implicitly fixed. Deploy large q to mimic steady-state. It works only for mode="Knoth".
r	number of quadrature nodes, dimension of the resulting linear equation system is equal to r+1 (one-sided) or r (two-sided).
with0	defines whether the first observation used for the RL calculation follows already $1 \cdot \delta$ or still $0 \cdot \delta$. With q additional flexibility is given.

Details

Based on Gan (1991) or Knoth (2003), the ARL is calculated for one-sided CUSUM control charts under drift. In case of Gan's framework, the usual ARL function with $\mu=m \cdot \delta$ is determined and recursively via $m-1, m-2, \dots, 1$ (or 0) the drift ARL determined. The framework of Knoth allows to calculate ARLs for varying parameters, such as control limits and distributional parameters. For details see the cited papers. Note that two-sided CUSUM charts under drift are difficult to treat.

Value

Returns a single value which resembles the ARL.

Author(s)

Sven Knoth

References

- F. F. Gan (1992), CUSUM control charts under linear drift, *Statistician* 41, 71-84.
- F. F. Gan (1996), Average Run Lengths for Cumulative Sum control chart under linear trend, *Applied Statistics* 45, 505-512.
- S. Knoth (2003), EWMA schemes with non-homogeneous transition kernels, *Sequential Analysis* 22, 241-255.

S. Knoth (2012), More on Control Charting under Drift, in: *Frontiers in Statistical Quality Control 10*, H.-J. Lenz, W. Schmid and P.-T. Wilrich (Eds.), Physica Verlag, Heidelberg, Germany, 53-68.

C. Zou, Y. Liu and Z. Wang (2009), Comparisons of control schemes for monitoring the means of processes subject to drifts, *Metrika* 70, 141-163.

See Also

xcusum.arl and xcusum.ad for zero-state and steady-state ARL computation of CUSUM control charts for the classical step change model.

Examples

```
## Gan (1992)
## Table 1
## original values are
# deltas arl
# 0.0001 475
# 0.0005 261
# 0.0010 187
# 0.0020 129
# 0.0050 76.3
# 0.0100 52.0
# 0.0200 35.2
# 0.0500 21.4
# 0.1000 15.0
# 0.5000 6.95
# 1.0000 5.16
# 3.0000 3.30
## Not run: k <- .25
h <- 8
r <- 50
DxDcusum.arl <- Vectorize(xDcusum.arl, "delta")
deltas <- c(0.0001, 0.0005, 0.001, 0.002, 0.005, 0.01, 0.02, 0.05, 0.1, 0.5, 1, 3)
arl.like.Gan <-
  round(DxDcusum.arl(k, h, deltas, r=r, with0=TRUE), digits=2)
arl.like.Knoth <-
  round(DxDcusum.arl(k, h, deltas, r=r, mode="Knoth", with0=TRUE), digits=2)
data.frame(deltas, arl.like.Gan, arl.like.Knoth)
## End(Not run)

## Zou et al. (2009)
## Table 1
## original values are
# delta arl1 arl2 arl3
# 0 ~ 1730
# 0.0005 345 412 470
# 0.001 231 275 317
# 0.005 86.6 98.6 112
# 0.01 56.9 61.8 69.3
# 0.05 22.6 21.6 22.7
# 0.1 15.4 14.7 14.2
# 0.5 6.60 5.54 5.17
```

```

# 1.0    4.63  3.80  3.45
# 2.0    3.17  2.67  2.32
# 3.0    2.79  2.04  1.96
# 4.0    2.10  1.98  1.74
## Not run:
k1 <- 0.25
k2 <- 0.5
k3 <- 0.75
h1 <- 9.660
h2 <- 5.620
h3 <- 3.904
deltas <- c(0.0005, 0.001, 0.005, 0.01, 0.05, 0.1, 0.5, 1:4)
arl1 <- c(round(xcusum.arl(k1, h1, 0, r=r), digits=2),
          round(DxDcusum.arl(k1, h1, deltas, r=r), digits=2))
arl2 <- c(round(xcusum.arl(k2, h2, 0), digits=2),
          round(DxDcusum.arl(k2, h2, deltas, r=r), digits=2))
arl3 <- c(round(xcusum.arl(k3, h3, 0, r=r), digits=2),
          round(DxDcusum.arl(k3, h3, deltas, r=r), digits=2))
data.frame(delta=c(0, deltas), arl1, arl2, arl3)
## End(Not run)

```

xDewma.arl

Compute ARLs of EWMA control charts under drift

Description

Computation of the (zero-state and other) Average Run Length (ARL) under drift for different types of EWMA control charts monitoring normal mean.

Usage

```
xDewma.arl(l, c, delta, zr = 0, hs = 0, sided = "one", limits = "fix",
           mode = "Gan", m = NULL, q = 1, r = 40, with0 = FALSE)
```

Arguments

l	smoothing parameter lambda of the EWMA control chart.
c	critical value (similar to alarm limit) of the EWMA control chart.
delta	true drift parameter.
zr	reflection border for the one-sided chart.
hs	so-called headstart (enables fast initial response).
sided	distinguish between one- and two-sided EWMA control chart by choosing "one" and "two", respectively.
limits	distinguishes between different control limits behavior.
mode	decide whether Gan's or Knoth's approach is used. Use "Gan" and "Knoth", respectively.

m	parameter used if mode="Gan". m is design parameter of Gan's approach. If m=NULL, then m will increased until the resulting ARL does not change anymore.
q	change point position. For $q = 1$ and $\mu = \mu_0$ and $\mu = \mu_1$, the usual zero-state ARLs for the in-control and out-of-control case, respectively, are calculated. For $q > 1$ and $\mu \neq 0$ conditional delays, that is, $E_q(L - q + 1 L \geq)$, will be determined. Note that $\mu_0=0$ is implicitly fixed. Deploy large q to mimic steady-state. It works only for mode="Knoth".
r	number of quadrature nodes, dimension of the resulting linear equation system is equal to r+1 (one-sided) or r (two-sided).
with0	defines whether the first observation used for the RL calculation follows already $1 \cdot \delta$ or still $0 \cdot \delta$. With q additional flexibility is given.

Details

Based on Gan (1991) or Knoth (2003), the ARL is calculated for EWMA control charts under drift. In case of Gan's framework, the usual ARL function with $\mu=m \cdot \delta$ is determined and recursively via m-1, m-2, ... 1 (or 0) the drift ARL determined. The framework of Knoth allows to calculate ARLs for varying parameters, such as control limits and distributional parameters. For details see the cited papers.

Value

Returns a single value which resembles the ARL.

Author(s)

Sven Knoth

References

- F. F. Gan (1991), EWMA control chart under linear drift, *J. Stat. Comput. Simulation* 38, 181-200.
- L. A. Aerne, C. W. Champ and S. E. Rigdon (1991), Evaluation of control charts under linear trend, *Commun. Stat., Theory Methods* 20, 3341-3349.
- S. Knoth (2003), EWMA schemes with non-homogeneous transition kernels, *Sequential Analysis* 22, 241-255.
- H. M. Fahmy and E. A. Elsayed (2006), Detection of linear trends in process mean, *International Journal of Production Research* 44, 487-504.
- S. Knoth (2012), More on Control Charting under Drift, in: *Frontiers in Statistical Quality Control 10*, H.-J. Lenz, W. Schmid and P.-T. Wilrich (Eds.), Physica Verlag, Heidelberg, Germany, 53-68.
- C. Zou, Y. Liu and Z. Wang (2009), Comparisons of control schemes for monitoring the means of processes subject to drifts, *Metrika* 70, 141-163.

See Also

xewma.arl and xewma.ad for zero-state and steady-state ARL computation of EWMA control charts for the classical step change model.

Examples

```
## Not run:
DxDewma.ar1 <- Vectorize(xDewma.ar1, "delta")
## Gan (1991)
## Table 1
## original values are
# delta  ar1E1  ar1E2  ar1E3
# 0      500   500   500
# 0.0001 482   460   424
# 0.0010 289   231   185
# 0.0020 210   162   129
# 0.0050 126   94.6  77.9
# 0.0100 81.7  61.3  52.7
# 0.0500 27.5  21.8  21.9
# 0.1000 17.0  14.2  15.3
# 1.0000 4.09  4.28  5.25
# 3.0000 2.60  2.90  3.43
#
lambda1 <- 0.676
lambda2 <- 0.242
lambda3 <- 0.047
h1 <- 2.204/sqrt(lambda1/(2-lambda1))
h2 <- 1.111/sqrt(lambda2/(2-lambda2))
h3 <- 0.403/sqrt(lambda3/(2-lambda3))
deltas <- c(.0001, .001, .002, .005, .01, .05, .1, 1, 3)
ar1E10 <- round(xewma.ar1(lambda1, h1, 0, sided="two"), digits=2)
ar1E1 <- c(ar1E10, round(DxDewma.ar1(lambda1, h1, deltas, sided="two", with0=TRUE),
  digits=2))
ar1E20 <- round(xewma.ar1(lambda2, h2, 0, sided="two"), digits=2)
ar1E2 <- c(ar1E20, round(DxDewma.ar1(lambda2, h2, deltas, sided="two", with0=TRUE),
  digits=2))
ar1E30 <- round(xewma.ar1(lambda3, h3, 0, sided="two"), digits=2)
ar1E3 <- c(ar1E30, round(DxDewma.ar1(lambda3, h3, deltas, sided="two", with0=TRUE),
  digits=2))
data.frame(delta=c(0, deltas), ar1E1, ar1E2, ar1E3)

## do the same with more digits for the alarm threshold
L0 <- 500
h1 <- xewma.crit(lambda1, L0, sided="two")
h2 <- xewma.crit(lambda2, L0, sided="two")
h3 <- xewma.crit(lambda3, L0, sided="two")
lambdas <- c(lambda1, lambda2, lambda3)
hs <- c(h1, h2, h3) * sqrt(lambdas/(2-lambdas))
hs
# compare with Gan's values 2.204, 1.111, 0.403
round(hs, digits=3)

ar1E10 <- round(xewma.ar1(lambda1, h1, 0, sided="two"), digits=2)
ar1E1 <- c(ar1E10, round(DxDewma.ar1(lambda1, h1, deltas, sided="two", with0=TRUE),
  digits=2))
ar1E20 <- round(xewma.ar1(lambda2, h2, 0, sided="two"), digits=2)
ar1E2 <- c(ar1E20, round(DxDewma.ar1(lambda2, h2, deltas, sided="two", with0=TRUE),
```

```

        digits=2))
arlE30 <- round(xewma.arl(lambda3, h3, 0, sided="two"), digits=2)
arlE3 <- c(arlE30, round(DxDewma.arl(lambda3, h3, deltas, sided="two", with0=TRUE),
        digits=2))
data.frame(delta=c(0, deltas), arlE1, arlE2, arlE3)

## Aerne et al. (1991) -- two-sided EWMA
## Table I (continued)
## original numbers are
#   delta  arlE1  arlE2  arlE3
# 0.000000 465.0  465.0  465.0
# 0.005623 77.01  85.93 102.68
# 0.007499 64.61  71.78  85.74
# 0.010000 54.20  59.74  71.22
# 0.013335 45.20  49.58  58.90
# 0.017783 37.76  41.06  48.54
# 0.023714 31.54  33.95  39.87
# 0.031623 26.36  28.06  32.68
# 0.042170 22.06  23.19  26.73
# 0.056234 18.49  19.17  21.84
# 0.074989 15.53  15.87  17.83
# 0.100000 13.07  13.16  14.55
# 0.133352 11.03  10.94  11.88
# 0.177828  9.33   9.12   9.71
# 0.237137  7.91   7.62   7.95
# 0.316228  6.72   6.39   6.52
# 0.421697  5.72   5.38   5.37
# 0.562341  4.88   4.54   4.44
# 0.749894  4.18   3.84   3.68
# 1.000000  3.58   3.27   3.07
#
lambda1 <- .133
lambda2 <- .25
lambda3 <- .5
cE1 <- 2.856
cE2 <- 2.974
cE3 <- 3.049
deltas <- 10^(-(18:0)/8)
arlE10 <- round(xewma.arl(lambda1, cE1, 0, sided="two"), digits=2)
arlE1 <- c(arlE10, round(DxDewma.arl(lambda1, cE1, deltas, sided="two"), digits=2))
arlE20 <- round(xewma.arl(lambda2, cE2, 0, sided="two"), digits=2)
arlE2 <- c(arlE20, round(DxDewma.arl(lambda2, cE2, deltas, sided="two"), digits=2))
arlE30 <- round(xewma.arl(lambda3, cE3, 0, sided="two"), digits=2)
arlE3 <- c(arlE30, round(DxDewma.arl(lambda3, cE3, deltas, sided="two"), digits=2))
data.frame(delta=c(0, round(deltas, digits=6)), arlE1, arlE2, arlE3)

## Fahmy/Elsayed (2006) -- two-sided EWMA
## Table 4 (Monte Carlo results, 10^4 replicates, change point at t=51!)
## original numbers are
#   delta   arl  s.e.
# 0.00 365.749 3.598
# 0.10 12.971 0.029

```



```

# 0.25 7.738 0.015
# 0.50 5.312 0.009
# 0.75 4.279 0.007
# 1.00 3.680 0.006
# 1.25 3.271 0.006
# 1.50 2.979 0.005
# 1.75 2.782 0.004
# 2.00 2.598 0.005
#
lambda <- 0.1
cE <- 2.7
deltas <- c(.1, (1:8)/4)
arlE1 <- c(round(xewma.arl(lambda, cE, 0, sided="two"), digits=3),
           round(DxDewma.arl(lambda, cE, deltas, sided="two"), digits=3))
arlE51 <- c(round(xewma.arl(lambda, cE, 0, sided="two", q=51)[51], digits=3),
            round(DxDewma.arl(lambda, cE, deltas, sided="two", mode="Knoth", q=51),
                  digits=3))
data.frame(delta=c(0, deltas), arlE1, arlE51)

## additional Monte Carlo results with 10^8 replicates
# delta arl.q=1 s.e. arl.q=51 s.e.
# 0.00 368.910 0.036 361.714 0.038
# 0.10 12.986 0.000 12.781 0.000
# 0.25 7.758 0.000 7.637 0.000
# 0.50 5.318 0.000 5.235 0.000
# 0.75 4.285 0.000 4.218 0.000
# 1.00 3.688 0.000 3.628 0.000
# 1.25 3.274 0.000 3.233 0.000
# 1.50 2.993 0.000 2.942 0.000
# 1.75 2.808 0.000 2.723 0.000
# 2.00 2.616 0.000 2.554 0.000

## Zou et al. (2009) -- one-sided EWMA
## Table 1
## original values are
# delta arl1 arl2 arl3
# 0 ~ 1730
# 0.0005 317 377 440
# 0.001 215 253 297
# 0.005 83.6 92.6 106
# 0.01 55.6 58.8 66.1
# 0.05 22.6 21.1 22.0
# 0.1 15.5 13.9 13.8
# 0.5 6.65 5.56 5.09
# 1.0 4.67 3.83 3.43
# 2.0 3.21 2.74 2.32
# 3.0 2.86 2.06 1.98
# 4.0 2.14 2.00 1.83
l1 <- 0.03479
l2 <- 0.11125
l3 <- 0.23052
c1 <- 2.711
c2 <- 3.033

```

```

c3 <- 3.161
zr <- -6
r <- 50
deltas <- c(0.0005, 0.001, 0.005, 0.01, 0.05, 0.1, 0.5, 1:4)
arl1 <- c(round(xewma.arl(11, c1, 0, zr=zr, r=r), digits=2),
          round(DxDewma.arl(11, c1, deltas, zr=zr, r=r), digits=2))
arl2 <- c(round(xewma.arl(12, c2, 0, zr=zr), digits=2),
          round(DxDewma.arl(12, c2, deltas, zr=zr, r=r), digits=2))
arl3 <- c(round(xewma.arl(13, c3, 0, zr=zr, r=r), digits=2),
          round(DxDewma.arl(13, c3, deltas, zr=zr, r=r), digits=2))
data.frame(delta=c(0, deltas), arl1, arl2, arl3)

## End(Not run)

```

xDgrsr.arl

Compute ARLs of Shiryaev-Roberts schemes under drift

Description

Computation of the (zero-state and other) Average Run Length (ARL) under drift for Shiryaev-Roberts schemes monitoring normal mean.

Usage

```

xDgrsr.arl(k, g, delta, zr = 0, hs = NULL, sided = "one", m = NULL,
mode = "Gan", q = 1, r = 30, with0 = FALSE)

```

Arguments

k	reference value of the Shiryaev-Roberts scheme.
g	control limit (alarm threshold) of Shiryaev-Roberts scheme.
delta	true drift parameter.
zr	reflection border for the one-sided chart.
hs	so-called headstart (enables fast initial response).
sided	distinguishes between one- and two-sided Shiryaev-Roberts schemes by choosing "one" and "two", respectively. Currently, the two-sided scheme is not implemented.
m	parameter used if mode="Gan". m is design parameter of Gan's approach. If m=NULL, then m will increased until the resulting ARL does not change anymore.
q	change point position. For $q = 1$ and $\mu = \mu_0$ and $\mu = \mu_1$, the usual zero-state ARLs for the in-control and out-of-control case, respectively, are calculated. For $q > 1$ and $\mu \neq 0$ conditional delays, that is, $E_q(L - q + 1 L \geq)$, will be determined. Note that $\mu_0=0$ is implicitly fixed. Deploy large q to mimic steady-state. It works only for mode="Knoth".
mode	decide whether Gan's or Knoth's approach is used. Use "Gan" and "Knoth", respectively. "Knoth" is not implemented yet.

`r` number of quadrature nodes, dimension of the resulting linear equation system is equal to $r+1$ (one-sided) or r (two-sided).

`with0` defines whether the first observation used for the RL calculation follows already $1*\delta$ or still $0*\delta$. With `q` additional flexibility is given.

Details

Based on Gan (1991) or Knoth (2003), the ARL is calculated for Shiryaev-Roberts schemes under drift. In case of Gan's framework, the usual ARL function with $\mu=m*\delta$ is determined and recursively via $m-1$, $m-2$, ... 1 (or 0) the drift ARL determined. The framework of Knoth allows to calculate ARLs for varying parameters, such as control limits and distributional parameters. For details see the cited papers.

Value

Returns a single value which resembles the ARL.

Author(s)

Sven Knoth

References

- F. F. Gan (1991), EWMA control chart under linear drift, *J. Stat. Comput. Simulation* 38, 181-200.
- S. Knoth (2003), EWMA schemes with non-homogeneous transition kernels, *Sequential Analysis* 22, 241-255.
- S. Knoth (2012), More on Control Charting under Drift, in: *Frontiers in Statistical Quality Control 10*, H.-J. Lenz, W. Schmid and P.-T. Wilrich (Eds.), Physica Verlag, Heidelberg, Germany, 53-68.
- C. Zou, Y. Liu and Z. Wang (2009), Comparisons of control schemes for monitoring the means of processes subject to drifts, *Metrika* 70, 141-163.

See Also

`xewma.arl` and `xewma.ad` for zero-state and steady-state ARL computation of EWMA control charts for the classical step change model.

Examples

```
## Not run:
## Monte Carlo example with 10^8 replicates
# delta      arl      s.e.
# 0.0001 381.8240 0.0304
# 0.0005 238.4630 0.0148
# 0.001 177.4061 0.0097
# 0.002 125.9055 0.0061
# 0.005 75.7574 0.0031
# 0.01 50.2203 0.0018
# 0.02 32.9458 0.0011
# 0.05 18.9213 0.0005
```

```

# 0.1    12.6054  0.0003
# 0.5     5.2157  0.0001
# 1       3.6537  0.0001
# 3       2.0289  0.0000
k <- .5
L0 <- 500
zr <- -7
r <- 50
g <- xgrsr.crit(k, L0, zr=zr, r=r)
DxDgrsr.arl <- Vectorize(xDgrsr.arl, "delta")
deltas <- c(0.0001, 0.0005, 0.001, 0.002, 0.005, 0.01, 0.02, 0.05, 0.1, 0.5, 1, 3)
arls <- round(DxDgrsr.arl(k, g, deltas, zr=zr, r=r), digits=4)
data.frame(deltas, arls)

## End(Not run)

```

xDshewhartrunrules.arl

Compute ARLs of Shewhart control charts with and without runs rules under drift

Description

Computation of the zero-state Average Run Length (ARL) under drift for Shewhart control charts with and without runs rules monitoring normal mean.

Usage

```
xDshewhartrunrules.arl(delta, c = 1, m = NULL, type = "12")
```

```
xDshewhartrunrulesFixedm.arl(delta, c = 1, m = 100, type = "12")
```

Arguments

delta	true drift parameter.
c	normalizing constant to ensure specific alarming behavior.
type	controls the type of Shewhart chart used, see details section.
m	parameter of Gan's approach. If m=NULL, then m will be increased until the resulting ARL does not change anymore.

Details

Based on Gan (1991), the ARL is calculated for Shewhart control charts with and without runs rules under drift. The usual ARL function with $\mu=m*\delta$ is determined and recursively via $m-1$, $m-2$, ... 1 (or 0) the drift ARL determined. `xDshewhartrunrulesFixedm.arl` is the actual work horse, while `xDshewhartrunrules.arl` provides a convenience wrapper. Note that Aerne et al. (1991) deployed a method that is quite similar to Gan's algorithm. For type see the help page of `xshewhartrunrules.arl`.

Value

Returns a single value which resembles the ARL.

Author(s)

Sven Knoth

References

F. F. Gan (1991), EWMA control chart under linear drift, *J. Stat. Comput. Simulation* 38, 181-200.

L. A. Aerne, C. W. Champ and S. E. Rigdon (1991), Evaluation of control charts under linear trend, *Commun. Stat., Theory Methods* 20, 3341-3349.

See Also

xshewhartrunrules.arl for zero-state ARL computation of Shewhart control charts with and without runs rules for the classical step change model.

Examples

```
## Aerne et al. (1991)
## Table I (continued)
## original numbers are
#   delta arl1of1 arl2of3 arl4of5 arl10
# 0.005623 136.67 120.90 105.34 107.08
# 0.007499 114.98 101.23 88.09 89.94
# 0.010000 96.03 84.22 73.31 75.23
# 0.013335 79.69 69.68 60.75 62.73
# 0.017783 65.75 57.38 50.18 52.18
# 0.023714 53.99 47.06 41.33 43.35
# 0.031623 44.15 38.47 33.99 36.00
# 0.042170 35.97 31.36 27.91 29.90
# 0.056234 29.21 25.51 22.91 24.86
# 0.074989 23.65 20.71 18.81 20.70
# 0.100000 19.11 16.79 15.45 17.29
# 0.133352 15.41 13.61 12.72 14.47
# 0.177828 12.41 11.03 10.50 12.14
# 0.237137 9.98 8.94 8.71 10.18
# 0.316228 8.02 7.25 7.26 8.45
# 0.421697 6.44 5.89 6.09 6.84
# 0.562341 5.17 4.80 5.15 5.48
# 0.749894 4.16 3.92 4.36 4.39
# 1.000000 3.35 3.22 3.63 3.52
c1of1 <- 3.069/3
c2of3 <- 2.1494/2
c4of5 <- 1.14
c10 <- 3.2425/3
DxDshewhartrunrules.arl <- Vectorize(xDshewhartrunrules.arl, "delta")
deltas <- 10^(-(18:0)/8)
arl1of1 <-
round(DxDshewhartrunrules.arl(deltas, c=c1of1, type="1"), digits=2)
```

```

ar12of3 <-
round(DxDshewhartrunrules.ar1(deltas, c=c2of3, type="12"), digits=2)
ar14of5 <-
round(DxDshewhartrunrules.ar1(deltas, c=c4of5, type="13"), digits=2)
ar110 <-
round(DxDshewhartrunrules.ar1(deltas, c=c10, type="SameSide10"), digits=2)
data.frame(delta=round(deltas, digits=6), ar11of1, ar12of3, ar14of5, ar110)

```

xewma.ad

Compute steady-state ARLs of EWMA control charts

Description

Computation of the steady-state Average Run Length (ARL) for different types of EWMA control charts monitoring normal mean.

Usage

```

xewma.ad(l, c, mu1, mu0=0, zr=0, z0=0, sided="one", limits="fix",
steady.state.mode="conditional", r=40)

```

Arguments

l	smoothing parameter lambda of the EWMA control chart.
c	critical value (similar to alarm limit) of the EWMA control chart.
mu1	out-of-control mean.
mu0	in-control mean.
zr	reflection border for the one-sided chart.
z0	restarting value of the EWMA sequence in case of a false alarm in <code>steady.state.mode="cyclical"</code> .
sided	distinguishes between one- and two-sided two-sided EWMA control chart by choosing "one" and "two", respectively.
limits	distinguishes between different control limits behavior.
steady.state.mode	distinguishes between two steady-state modes – conditional and cyclical.
r	number of quadrature nodes, dimension of the resulting linear equation system is equal to r+1 (one-sided) or r (two-sided).

Details

xewma.ad determines the steady-state Average Run Length (ARL) by numerically solving the related ARL integral equation by means of the Nystroem method based on Gauss-Legendre quadrature and using the power method for deriving the largest in magnitude eigenvalue and the related left eigenfunction.

Value

Returns a single value which resembles the steady-state ARL.

Author(s)

Sven Knoth

References

R. B. Crosier (1986), A new two-sided cumulative quality control scheme, *Technometrics* 28, 187-194.

S. V. Crowder (1987), A simple method for studying run-length distributions of exponentially weighted moving average charts, *Technometrics* 29, 401-407.

J. M. Lucas and M. S. Saccucci (1990), Exponentially weighted moving average control schemes: Properties and enhancements, *Technometrics* 32, 1-12.

See Also

xewma.arl for zero-state ARL computation and xcusum.ad for the steady-state ARL of CUSUM control charts.

Examples

```
## comparison of zero-state (= worst case ) and steady-state performance
## for two-sided EWMA control charts

l <- .1
c <- xewma.crit(l,500,sided="two")
mu <- c(0,.5,1,1.5,2)
arl <- sapply(mu,l=l,c=c,sided="two",xewma.arl)
ad <- sapply(mu,l=l,c=c,sided="two",xewma.ad)
round(cbind(mu,arl,ad),digits=2)

## Lucas/Saccucci (1990)
## two-sided EWMA

## with fixed limits
l1 <- .5
l2 <- .03
c1 <- 3.071
c2 <- 2.437
mu <- c(0,.25,.5,.75,1,1.5,2,2.5,3,3.5,4,5)
ad1 <- sapply(mu,l=l1,c=c1,sided="two",xewma.ad)
ad2 <- sapply(mu,l=l2,c=c2,sided="two",xewma.ad)
round(cbind(mu,ad1,ad2),digits=2)

## original results are (in Table 3)
## 0.00 499. 480.
## 0.25 254. 74.1
## 0.50 88.4 28.6
```

```
## 0.75 35.7 17.3
## 1.00 17.3 12.5
## 1.50 6.44 8.00
## 2.00 3.58 5.95
## 2.50 2.47 4.78
## 3.00 1.91 4.02
## 3.50 1.58 3.49
## 4.00 1.36 3.09
## 5.00 1.10 2.55
```

```
xewma.arl
```

```
Compute ARLs of EWMA control charts
```

Description

Computation of the (zero-state) Average Run Length (ARL) for different types of EWMA control charts monitoring normal mean.

Usage

```
xewma.arl(l,c,mu,zr=0,hs=0,sided="one",limits="fix",q=1,r=40)
```

Arguments

<code>l</code>	smoothing parameter lambda of the EWMA control chart.
<code>c</code>	critical value (similar to alarm limit) of the EWMA control chart.
<code>mu</code>	true mean.
<code>zr</code>	reflection border for the one-sided chart.
<code>hs</code>	so-called headstart (enables fast initial response).
<code>sided</code>	distinguishes between one- and two-sided EWMA control chart by choosing "one" and "two", respectively.
<code>limits</code>	distinguishes between different control limits behavior.
<code>q</code>	change point position. For $q = 1$ and $\mu = \mu_0$ and $\mu = \mu_1$, the usual zero-state ARLs for the in-control and out-of-control case, respectively, are calculated. For $q > 1$ and $\mu = 0$ conditional delays, that is, $E_q(L - q + 1 L \geq q)$, will be determined. Note that $\mu_0=0$ is implicitly fixed.
<code>r</code>	number of quadrature nodes, dimension of the resulting linear equation system is equal to $r+1$ (one-sided) or r (two-sided).

Details

In case of the EWMA chart with fixed control limits, `xewma.arl` determines the Average Run Length (ARL) by numerically solving the related ARL integral equation by means of the Nystroem method based on Gauss-Legendre quadrature. If `limits` is not "fix", then the method presented in Knoth (2003) is utilized. Note that for one-sided EWMA charts (`sided="one"`), only "vacl" and "stat" are deployed, while for two-sided ones (`sided="two"`) also "fir", "both" (combination of "fir" and "vacl"), and "Steiner" are implemented. For details see Knoth (2004).

Value

Except for the fixed limits EWMA charts it returns a single value which resembles the ARL. For fixed limits charts, it returns a vector of length q which resembles the ARL and the sequence of conditional expected delays for $q=1$ and $q>1$, respectively.

Author(s)

Sven Knoth

References

- K.-H. Waldmann (1986), Bounds for the distribution of the run length of geometric moving average charts, *Appl. Statist.* 35, 151-158.
- S. V. Crowder (1987), A simple method for studying run-length distributions of exponentially weighted moving average charts, *Technometrics* 29, 401-407.
- J. M. Lucas and M. S. Saccucci (1990), Exponentially weighted moving average control schemes: Properties and enhancements, *Technometrics* 32, 1-12.
- S. Chandrasekaran, J. R. English and R. L. Disney (1995), Modeling and analysis of EWMA control schemes with variance-adjusted control limits, *IIE Transactions* 277, 282-290.
- T. R. Rhoads, D. C. Montgomery and C. M. Mastrangelo (1996), Fast initial response scheme for exponentially weighted moving average control chart, *Quality Engineering* 9, 317-327.
- S. H. Steiner (1999), EWMA control charts with time-varying control limits and fast initial response, *Journal of Quality Technology* 31, 75-86.
- S. Knoth (2003), EWMA schemes with non-homogeneous transition kernels, *Sequential Analysis* 22, 241-255.
- S. Knoth (2004), Fast initial response features for EWMA Control Charts, *Statistical Papers* 46, 47-64.

See Also

xcusum.arl for zero-state ARL computation of CUSUM control charts and xewma.ad for the steady-state ARL.

Examples

```
## Waldmann (1986), one-sided EWMA
l <- .75
round(xewma.arl(1,2*sqrt((2-l)/1),0,zr=-4*sqrt((2-l)/1)),digits=1)
l <- .5
round(xewma.arl(1,2*sqrt((2-l)/1),0,zr=-4*sqrt((2-l)/1)),digits=1)
## original values are 209.3 and 3907.5 (in Table 2).

## Waldmann (1986), two-sided EWMA with fixed control limits
l <- .75
round(xewma.arl(1,2*sqrt((2-l)/1),0,sided="two"),digits=1)
l <- .5
round(xewma.arl(1,2*sqrt((2-l)/1),0,sided="two"),digits=1)
## original values are 104.0 and 1952 (in Table 1).
```

```

## Crowder (1987), two-sided EWMA with fixed control limits
l1 <- .5
l2 <- .05
c <- 2
mu <- (0:16)/4
ar11 <- sapply(mu,l=l1,c=c,sided="two",xewma.ar1)
ar12 <- sapply(mu,l=l2,c=c,sided="two",xewma.ar1)
round(cbind(mu,ar11,ar12),digits=2)

## original results are (in Table 1)
## 0.00 26.45 127.53
## 0.25 20.12 43.94
## 0.50 11.89 18.97
## 0.75 7.29 11.64
## 1.00 4.91 8.38
## 1.25 3.95* 6.56
## 1.50 2.80 5.41
## 1.75 2.29 4.62
## 2.00 1.94 4.04
## 2.25 1.70 3.61
## 2.50 1.51 3.26
## 2.75 1.37 2.99
## 3.00 1.26 2.76
## 3.25 1.18 2.56
## 3.50 1.12 2.39
## 3.75 1.08 2.26
## 4.00 1.05 2.15 (* -- in Crowder (1987) typo!?)

## Lucas/Saccucci (1990)
## two-sided EWMA

## with fixed limits
l1 <- .5
l2 <- .03
c1 <- 3.071
c2 <- 2.437
mu <- c(0,.25,.5,.75,1,1.5,2,2.5,3,3.5,4,5)
ar11 <- sapply(mu,l=l1,c=c1,sided="two",xewma.ar1)
ar12 <- sapply(mu,l=l2,c=c2,sided="two",xewma.ar1)
round(cbind(mu,ar11,ar12),digits=2)

## original results are (in Table 3)
## 0.00 500. 500.
## 0.25 255. 76.7
## 0.50 88.8 29.3
## 0.75 35.9 17.6
## 1.00 17.5 12.6
## 1.50 6.53 8.07
## 2.00 3.63 5.99
## 2.50 2.50 4.80
## 3.00 1.93 4.03
## 3.50 1.58 3.49

```

```

## 4.00  1.34  3.11
## 5.00  1.07  2.55

## Not run:
## with fir feature
l1 <- .5
l2 <- .03
c1 <- 3.071
c2 <- 2.437
hs1 <- c1/2
hs2 <- c2/2
mu <- c(0,.5,1,2,3,5)
ar11 <- sapply(mu,l=l1,c=c1,hs=hs1,sided="two",limits="fir",xewma.ar1)
ar12 <- sapply(mu,l=l2,c=c2,hs=hs2,sided="two",limits="fir",xewma.ar1)
round(cbind(mu,ar11,ar12),digits=2)

## original results are (in Table 5)
## 0.0 487.  406.
## 0.5  86.1  18.4
## 1.0  15.9   7.36
## 2.0   2.87  3.43
## 3.0   1.45  2.34
## 5.0   1.01  1.57

## Chandrasekaran, English, Disney (1995)
## two-sided EWMA with fixed and variance adjusted limits (vacl)

l1 <- .25
l2 <- .1
c1s <- 2.9985
c1n <- 3.0042
c2s <- 2.8159
c2n <- 2.8452
mu <- c(0,.25,.5,.75,1,2)
ar11s <- sapply(mu,l=l1,c=c1s,sided="two",xewma.ar1)
ar11n <- sapply(mu,l=l1,c=c1n,sided="two",limits="vacl",xewma.ar1)
ar12s <- sapply(mu,l=l2,c=c2s,sided="two",xewma.ar1)
ar12n <- sapply(mu,l=l2,c=c2n,sided="two",limits="vacl",xewma.ar1)
round(cbind(mu,ar11s,ar11n,ar12s,ar12n),digits=2)

## original results are (in Table 2)
## 0.00 500.  500.  500.  500.
## 0.25 170.09 167.54 105.90 96.6
## 0.50  48.14  45.65  31.08  24.35
## 0.75  20.02  19.72  15.71  10.74
## 1.00  11.07   9.37  10.23   6.35
## 2.00   3.59   2.64   4.32   2.73

## The results in Chandrasekaran, English, Disney (1995) are not
## that accurate. Let us consider the more appropriate comparison

c1s <- xewma.crit(l1,500,sided="two")
c1n <- xewma.crit(l1,500,sided="two",limits="vacl")

```

```

c2s <- xewma.crit(12,500,sided="two")
c2n <- xewma.crit(12,500,sided="two",limits="vacl")
mu <- c(0,.25,.5,.75,1,2)
arl1s <- sapply(mu,l=11,c=c1s,sided="two",xewma.arl)
arl1n <- sapply(mu,l=11,c=c1n,sided="two",limits="vacl",xewma.arl)
arl2s <- sapply(mu,l=12,c=c2s,sided="two",xewma.arl)
arl2n <- sapply(mu,l=12,c=c2n,sided="two",limits="vacl",xewma.arl)
round(cbind(mu,arl1s,arl1n,arl2s,arl2n),digits=2)

## which demonstrate the abilities of the variance-adjusted limits
## scheme more explicitly.

## Rhoads, Montgomery, Mastrangelo (1996)
## two-sided EWMA with fixed and variance adjusted limits (vacl),
## with fir and both features

l <- .03
c <- 2.437
mu <- c(0,.5,1,1.5,2,3,4)
s1 <- sqrt(1*(2-1))
arlfix <- sapply(mu,l=1,c=c,sided="two",xewma.arl)
arlvacl <- sapply(mu,l=1,c=c,sided="two",limits="vacl",xewma.arl)
arlfir <- sapply(mu,l=1,c=c,hs=c/2,sided="two",limits="fir",xewma.arl)
arlboth <- sapply(mu,l=1,c=c,hs=c/2*s1,sided="two",limits="both",xewma.arl)
round(cbind(mu,arlfix,arlvacl,arlfir,arlboth),digits=1)

## original results are (in Table 1)
## 0.0 477.3* 427.9* 383.4* 286.2*
## 0.5 29.7 20.0 18.6 12.8
## 1.0 12.5 6.5 7.4 3.6
## 1.5 8.1 3.3 4.6 1.9
## 2.0 6.0 2.2 3.4 1.4
## 3.0 4.0 1.3 2.4 1.0
## 4.0 3.1 1.1 1.9 1.0
## * -- the in-control values differ sustainably from the true values!

## Steiner (1999)
## two-sided EWMA control charts with various modifications

## fixed vs. variance adjusted limits

l <- .05
c <- 3
mu <- c(0,.25,.5,.75,1,1.5,2,2.5,3,3.5,4)
arlfix <- sapply(mu,l=1,c=c,sided="two",xewma.arl)
arlvacl <- sapply(mu,l=1,c=c,sided="two",limits="vacl",xewma.arl)
round(cbind(mu,arlfix,arlvacl),digits=1)

## original results are (in Table 2)
## 0.00 1379.0 1353.0
## 0.25 135.0 127.0
## 0.50 37.4 32.5
## 0.75 20.0 15.6

```

```

## 1.00  13.5    9.0
## 1.50   8.3    4.5
## 2.00   6.0    2.8
## 2.50   4.8    2.0
## 3.00   4.0    1.6
## 3.50   3.4    1.3
## 4.00   3.0    1.1

## fir, both, and Steiner's modification

l <- .03
cfir <- 2.44
cboth <- 2.54
cstein <- 2.55
hsfir <- cfir/2
hsboth <- cboth/2*sqrt(1*(2-l))
mu <- c(0,.5,1,1.5,2,3,4)
arlfir <- sapply(mu,l=1,c=cfir,hs=hsfir,sided="two",limits="fir",xewma.arl)
arlbth <- sapply(mu,l=1,c=cboth,hs=hsboth,sided="two",limits="both",xewma.arl)
arlstein <- sapply(mu,l=1,c=cstein,sided="two",limits="Steiner",xewma.arl)
round(cbind(mu,arlfir,arlbth,arlstein),digits=1)

## original values are (in Table 5)
## 0.0 383.0 384.0 391.0
## 0.5 18.6 14.9 13.8
## 1.0 7.4 3.9 3.6
## 1.5 4.6 2.0 1.8
## 2.0 3.4 1.4 1.3
## 3.0 2.4 1.1 1.0
## 4.0 1.9 1.0 1.0

## SAS/QC manual 1999
## two-sided EWMA control charts with fixed limits

l <- .25
c <- 3
mu <- 1
print(xewma.arl(l,c,mu,sided="two"),digits=11)

# original value is 11.154267016.

## Some recent examples for one-sided EWMA charts
## with varying limits and in the so-called stationary mode

# 1. varying limits = "vacl"

lambda <- .1
L0 <- 500

## Monte Carlo results (10^9 replicates)
# mu  ARL  s.e.
# 0  500.00  0.0160
# 0.5  21.637  0.0006

```

```

# 1      6.7596  0.0001
# 1.5    3.5398  0.0001
# 2      2.3038  0.0000
# 2.5    1.7004  0.0000
# 3      1.3675  0.0000

zr <- -6
r <- 50
c <- xewma.crit(lambda, L0, zr=zr, limits="vacl", r=r)
Mxewma.arl <- Vectorize(xewma.arl, "mu")
mus <- (0:6)/2
arls <- round(Mxewma.arl(lambda, c, mus, zr=zr, limits="vacl", r=r), digits=4)
data.frame(mus, arls)

# 2. stationary mode, i. e. limits = "stat"

## Monte Carlo results (10^9 replicates)
# mu    ARL    s.e.
# 0     500.00  0.0159
# 0.5   22.313  0.0006
# 1     7.2920  0.0001
# 1.5   3.9064  0.0001
# 2     2.5131  0.0000
# 2.5   1.7983  0.0000
# 3     1.4029  0.0000

c <- xewma.crit(lambda, L0, zr=zr, limits="stat", r=r)
arls <- round(Mxewma.arl(lambda, c, mus, zr=zr, limits="stat", r=r), digits=4)
data.frame(mus, arls)

## End(Not run)

```

xewma.arl.prerun	<i>Compute ARLs of EWMA control charts in case of estimated parameters</i>
------------------	--

Description

Computation of the (zero-state) Average Run Length (ARL) for different types of EWMA control charts monitoring normal mean if the in-control mean, standard deviation, or both are estimated by a pre run.

Usage

```
xewma.arl.prerun(l, c, mu, zr=0, hs=0, sided="two", limits="fix", q=1,
size=100, df=NULL, estimated="mu", qm.mu=30, qm.sigma=30, truncate=1e-10)
```

```
xewma.crit.prerun(l, L0, mu, zr=0, hs=0, sided="two", limits="fix", size=100,
df=NULL, estimated="mu", qm.mu=30, qm.sigma=30, truncate=1e-10,
c.error=1e-12, L.error=1e-9, OUTPUT=FALSE)
```

Arguments

l	smoothing parameter lambda of the EWMA control chart.
c	critical value (similar to alarm limit) of the EWMA control chart.
mu	true mean shift.
zr	reflection border for the one-sided chart.
hs	so-called headstart (give fast initial response).
sided	distinguish between one- and two-sided EWMA control chart by choosing "one" and "two", respectively.
limits	distinguish between different control limits behavior.
q	change point position. For $q = 1$ and $\mu = \mu_0$ and $\mu = \mu_1$, the usual zero-state ARLs for the in-control and out-of-control case, respectively, are calculated. For $q > 1$ and $\mu \neq 0$ conditional delays, that is, $E_q(L - q + 1 L \geq q)$, will be determined. Note that $\mu_0 = 0$ is implicitly fixed.
size	pre run sample size.
df	Degrees of freedom of the pre run variance estimator. Typically it is simply size - 1. If the pre run is collected in batches, then also other values are needed.
estimated	name the parameter to be estimated within the "mu", "sigma", "both".
qm.mu	number of quadrature nodes for convoluting the mean uncertainty.
qm.sigma	number of quadrature nodes for convoluting the standard deviation uncertainty.
truncate	size of truncated tail.
L0	in-control ARL.
c.error	error bound for two succeeding values of the critical value during applying the secant rule.
L.error	error bound for the ARL level L0 during applying the secant rule.
OUTPUT	activate or deactivate additional output.

Details

Essentially, the ARL function `xewma.arl` is convoluted with the distribution of the sample mean, standard deviation or both. For details see Jones/Champ/Rigdon (2001) and Knoth (2014?).

Value

Returns a single value which resembles the ARL.

Author(s)

Sven Knoth

References

- L. A. Jones, C. W. Champ, S. E. Rigdon (2001), The performance of exponentially weighted moving average charts with estimated parameters, *Technometrics* 43, 156-167.
- S. Knoth (2003), EWMA schemes with non-homogeneous transition kernels, *Sequential Analysis* 22, 241-255.
- S. Knoth (2004), Fast initial response features for EWMA Control Charts, *Statistical Papers* 46, 47-64.
- S. Knoth (2014?), tbd, *tbd*, tbd-tbd.

See Also

xewma.arl for the usual zero-state ARL computation.

Examples

```
## Jones/Champ/Rigdon (2001)

c4m <- function(m, n) sqrt(2)*gamma( (m*(n-1)+1)/2 )/sqrt( m*(n-1) )/gamma( m*(n-1)/2 )

n <- 5 # sample size
m <- 20 # pre run with 20 samples of size n = 5
C4m <- c4m(m, n) # needed for bias correction

# Table 1, 3rd column
lambda <- 0.2
L <- 2.636

xewma.ARL <- Vectorize("xewma.arl", "mu")
xewma.ARL.prerun <- Vectorize("xewma.arl.prerun", "mu")

mu <- c(0, .25, .5, 1, 1.5, 2)
ARL <- round(xewma.ARL(lambda, L, mu, sided="two"), digits=2)
p.ARL <- round(xewma.ARL.prerun(lambda, L/C4m, mu, sided="two",
size=m, df=m*(n-1), estimated="both", qm.mu=70), digits=2)

# Monte-Carlo with 10^8 repetitions: 200.325 (0.020) and 144.458 (0.022)
cbind(mu, ARL, p.ARL)

## Not run:
# Figure 5, subfigure r = 0.2
mu_ <- (0:85)/40
ARL_ <- round(xewma.ARL(lambda, L, mu_, sided="two"), digits=2)
p.ARL_ <- round(xewma.ARL.prerun(lambda, L/C4m, mu_, sided="two",
size=m, df=m*(n-1), estimated="both"), digits=2)

plot(mu_, ARL_, type="l", xlab=expression(delta), ylab="ARL", xlim=c(0,2))
abline(v=0, h=0, col="grey", lwd=.7)
points(mu, ARL, pch=5)
lines(mu_, p.ARL_, col="blue")
points(mu, p.ARL, pch=18, col="blue")
```



```

legend("topright", c("Known", "Estimated"), col=c("black", "blue"),
      lty=1, pch=c(5, 18))

## End(Not run)

```

xewma.crit

Compute critical values of EWMA control charts

Description

Computation of the critical values (similar to alarm limits) for different types of EWMA control charts monitoring normal mean.

Usage

```
xewma.crit(l,L0,mu0=0,zr=0,hs=0,sided="one",limits="fix",r=40,c0=NULL)
```

Arguments

l	smoothing parameter lambda of the EWMA control chart.
L0	in-control ARL.
mu0	in-control mean.
zr	reflection border for the one-sided chart.
hs	so-called headstart (enables fast initial response).
sided	distinguishes between one- and two-sided two-sided EWMA control chart by choosing "one" and "two", respectively.
limits	distinguishes between different control limits behavior.
r	number of quadrature nodes, dimension of the resulting linear equation system is equal to r+1 (one-sided) or r (two-sided).
c0	starting value for iteration rule.

Details

xewma.crit determines the critical values (similar to alarm limits) for given in-control ARL L0 by applying secant rule and using xewma.arl().

Value

Returns a single value which resembles the critical value c.

Author(s)

Sven Knoth

References

S. V. Crowder (1989), Design of exponentially weighted moving average schemes, *Journal of Quality Technology* 21, 155-162.

See Also

xewma.arl for zero-state ARL computation.

Examples

```
l <- .1
incontrolARL <- c(500,5000,50000)
sapply(incontrolARL,l=1,sided="two",xewma.crit,r=35) # accuracy with 35 nodes
sapply(incontrolARL,l=1,sided="two",xewma.crit)      # accuracy with 40 nodes
sapply(incontrolARL,l=1,sided="two",xewma.crit,r=50) # accuracy with 50 nodes

## Crowder (1989)
## two-sided EWMA control charts with fixed limits

l <- c(.05,.1,.15,.2,.25)
L0 <- 250
round(sapply(l,L0=L0,sided="two",xewma.crit),digits=2)

## original values are 2.32, 2.55, 2.65, 2.72, and 2.76.
```

xewma.q

Compute RL quantiles of EWMA control charts

Description

Computation of quantiles of the Run Length (RL) for EWMA control charts monitoring normal mean.

Usage

```
xewma.q(l, c, mu, alpha, zr=0, hs=0, sided="two", limits="fix", q=1, r=40)

xewma.q.crit(l, L0, mu, alpha, zr=0, hs=0, sided="two", limits="fix", r=40,
c.error=1e-12, a.error=1e-9, OUTPUT=FALSE)
```

Arguments

l	smoothing parameter lambda of the EWMA control chart.
c	critical value (similar to alarm limit) of the EWMA control chart.
mu	true mean.
alpha	quantile level.
zr	reflection border for the one-sided chart.

hs	so-called headstart (enables fast initial response).
sided	distinguishes between one- and two-sided EWMA control chart by choosing "one" and "two", respectively.
limits	distinguishes between different control limits behavior.
q	change point position. For $q = 1$ and $\mu = \mu_0$ and $\mu = \mu_1$, the usual zero-state ARLs for the in-control and out-of-control case, respectively, are calculated. For $q > 1$ and $\mu = 0$ conditional delays, that is, $E_q(L - q + 1 L \geq)$, will be determined. Note that $\mu_0=0$ is implicitly fixed.
r	number of quadrature nodes, dimension of the resulting linear equation system is equal to $r+1$ (one-sided) or r (two-sided).
L0	in-control quantile value.
c.error	error bound for two succeeding values of the critical value during applying the secant rule.
a.error	error bound for the quantile level alpha during applying the secant rule.
OUTPUT	activate or deactivate additional output.

Details

Instead of the popular ARL (Average Run Length) quantiles of the EWMA stopping time (Run Length) are determined. The algorithm is based on Waldmann's survival function iteration procedure. If `limits` is not "fix", then the method presented in Knoth (2003) is utilized. Note that for one-sided EWMA charts (`sided="one"`), only "vacl" and "stat" are deployed, while for two-sided ones (`sided="two"`) also "fir", "both" (combination of "fir" and "vacl"), and "Steiner" are implemented. For details see Knoth (2004).

Value

Returns a single value which resembles the RL quantile of order q .

Author(s)

Sven Knoth

References

- F. F. Gan (1993), An optimal design of EWMA control charts based on the median run length, *J. Stat. Comput. Simulation* 45, 169-184.
- S. Knoth (2003), EWMA schemes with non-homogeneous transition kernels, *Sequential Analysis* 22, 241-255.
- S. Knoth (2004), Fast initial response features for EWMA Control Charts, *Statistical Papers* 46, 47-64.
- S. Knoth (2015), Run length quantiles of EWMA control charts monitoring normal mean or/and variance, *International Journal of Production Research* 53, 4629-4647.
- K.-H. Waldmann (1986), Bounds for the distribution of the run length of geometric moving average charts, *Appl. Statist.* 35, 151-158.

See Also

xewma.arl for zero-state ARL computation of EWMA control charts.

Examples

```
## Gan (1993), two-sided EWMA with fixed control limits
## some values of his Table 1 -- any median RL should be 500
XEWMA.Q <- Vectorize("xewma.q", c("l", "c"))
G.lambda <- c(.05, .1, .15, .2, .25)
G.h <- c(.441, .675, .863, 1.027, 1.177)
MEDIAN <- ceiling(XEWMA.Q(G.lambda, G.h/sqrt(G.lambda/(2-G.lambda)),
0, .5, sided="two"))
print(cbind(G.lambda, MEDIAN))

## increase accuracy of thresholds

# (i) calculate threshold for given in-control median value by
#   deploying secant rule
XEWMA.q.crit <- Vectorize("xewma.q.crit", "l")

# (ii) re-calculate the thresholds and remove the standardization step
L0 <- 500
G.h.new <- XEWMA.q.crit(G.lambda, L0, 0, .5, sided="two")
G.h.new <- round(G.h.new * sqrt(G.lambda/(2-G.lambda)), digits=5)

# (iii) compare Gan's original values and the new ones with 5 digits
print(cbind(G.lambda, G.h.new, G.h))

# (iv) calculate the new medians
MEDIAN <- ceiling(XEWMA.Q(G.lambda, G.h.new/sqrt(G.lambda/(2-G.lambda)),
0, .5, sided="two"))
print(cbind(G.lambda, MEDIAN))
```

xewma.q.prerun

Compute RL quantiles of EWMA control charts in case of estimated parameters

Description

Computation of quantiles of the Run Length (RL) for EWMA control charts monitoring normal mean if the in-control mean, standard deviation, or both are estimated by a pre run.

Usage

```
xewma.q.prerun(l, c, mu, p, zr=0, hs=0, sided="two", limits="fix", q=1, size=100,
df=NULL, estimated="mu", qm.mu=30, qm.sigma=30, truncate=1e-10, bound=1e-10)
```

```
xewma.q.crit.prerun(l, L0, mu, p, zr=0, hs=0, sided="two", limits="fix", size=100,
df=NULL, estimated="mu", qm.mu=30, qm.sigma=30, truncate=1e-10, bound=1e-10,
c.error=1e-10, p.error=1e-9, OUTPUT=FALSE)
```

Arguments

l	smoothing parameter lambda of the EWMA control chart.
c	critical value (similar to alarm limit) of the EWMA control chart.
mu	true mean shift.
p	quantile level.
zr	reflection border for the one-sided chart.
hs	so-called headstart (give fast initial response).
sided	distinguish between one- and two-sided EWMA control chart by choosing "one" and "two", respectively.
limits	distinguish between different control limits behavior.
q	change point position. For $q = 1$ and $\mu = \mu_0$ and $\mu = \mu_1$, the usual zero-state ARLs for the in-control and out-of-control case, respectively, are calculated. For $q > 1$ and $\mu^l = 0$ conditional delays, that is, $E_q(L - q + 1 L \geq)$, will be determined. Note that $\mu_0=0$ is implicitly fixed.
size	pre run sample size.
df	Degrees of freedom of the pre run variance estimator. Typically it is simply size - 1. If the pre run is collected in batches, then also other values are needed.
estimated	name the parameter to be estimated within the "mu", "sigma", "both".
qm.mu	number of quadrature nodes for convoluting the mean uncertainty.
qm.sigma	number of quadrature nodes for convoluting the standard deviation uncertainty.
truncate	size of truncated tail.
bound	control when the geometric tail kicks in; the larger the quicker and less accurate; bound should be larger than 0 and less than 0.001.
L0	in-control quantile value.
c.error	error bound for two succeeding values of the critical value during applying the secant rule.
p.error	error bound for the quantile level p during applying the secant rule.
OUTPUT	activate or deactivate additional output.

Details

Essentially, the ARL function xewma.q is convoluted with the distribution of the sample mean, standard deviation or both. For details see Jones/Champ/Rigdon (2001) and Knoth (2014?).

Value

Returns a single value which resembles the RL quantile of order q.

Author(s)

Sven Knoth

References

- L. A. Jones, C. W. Champ, S. E. Rigdon (2001), The performance of exponentially weighted moving average charts with estimated parameters, *Technometrics* 43, 156-167.
- S. Knoth (2003), EWMA schemes with non-homogeneous transition kernels, *Sequential Analysis* 22, 241-255.
- S. Knoth (2004), Fast initial response features for EWMA Control Charts, *Statistical Papers* 46, 47-64.
- S. Knoth (2014?), tbd, *tbd*, tbd-tbd.
- K.-H. Waldmann (1986), Bounds for the distribution of the run length of geometric moving average charts, *Appl. Statist.* 35, 151-158.

See Also

xewma.q for the usual RL quantiles computation of EWMA control charts.

Examples

```
## Jones/Champ/Rigdon (2001)

c4m <- function(m, n) sqrt(2)*gamma( (m*(n-1)+1)/2 )/sqrt( m*(n-1) )/gamma( m*(n-1)/2 )

n <- 5 # sample size
m <- 20 # pre run with 20 samples of size n = 5
C4m <- c4m(m, n) # needed for bias correction

# Table 1, 3rd column
lambda <- 0.2
L <- 2.636

xewma.Q <- Vectorize("xewma.q", "mu")
xewma.Q.prerun <- Vectorize("xewma.q.prerun", "mu")

mu <- c(0, .25, .5, 1, 1.5, 2)
Q1 <- ceiling(xewma.Q(lambda, L, mu, 0.1, sided="two"))
Q2 <- ceiling(xewma.Q(lambda, L, mu, 0.5, sided="two"))
Q3 <- ceiling(xewma.Q(lambda, L, mu, 0.9, sided="two"))

cbind(mu, Q1, Q2, Q3)

## Not run:
p.Q1 <- xewma.Q.prerun(lambda, L/C4m, mu, 0.1, sided="two",
size=m, df=m*(n-1), estimated="both")
p.Q2 <- xewma.Q.prerun(lambda, L/C4m, mu, 0.5, sided="two",
size=m, df=m*(n-1), estimated="both")
p.Q3 <- xewma.Q.prerun(lambda, L/C4m, mu, 0.9, sided="two",
size=m, df=m*(n-1), estimated="both")

cbind(mu, p.Q1, p.Q2, p.Q3)

## End(Not run)
```

```
## original values are
#   mu Q1  Q2  Q3 p.Q1 p.Q2 p.Q3
# 0.00 25 140 456  13  73  345
# 0.25 12  56 174   9  46  253
# 0.50  7  20  56   6  20  101
# 1.00  4   7  15   3   7   18
# 1.50  3   4   7   2   4    8
# 2.00  2   3   5   2   3    5
```

xewma.sf

Compute the survival function of EWMA run length

Description

Computation of the survival function of the Run Length (RL) for EWMA control charts monitoring normal mean.

Usage

```
xewma.sf(l, c, mu, n, zr=0, hs=0, sided="one", limits="fix", q=1, r=40)
```

Arguments

l	smoothing parameter lambda of the EWMA control chart.
c	critical value (similar to alarm limit) of the EWMA control chart.
mu	true mean.
n	calculate sf up to value n.
zr	reflection border for the one-sided chart.
hs	so-called headstart (enables fast initial response).
sided	distinguishes between one- and two-sided EWMA control chart by choosing "one" and "two", respectively.
limits	distinguishes between different control limits behavior.
q	change point position. For $q = 1$ and $\mu = \mu_0$ and $\mu = \mu_1$, the usual zero-state situation for the in-control and out-of-control case, respectively, are calculated. Note that $\mu_0=0$ is implicitly fixed.
r	number of quadrature nodes, dimension of the resulting linear equation system is equal to $r+1$ (one-sided) or r (two-sided).

Details

The survival function $P(L > n)$ and derived from it also the cdf $P(L \leq n)$ and the pmf $P(L = n)$ illustrate the distribution of the EWMA run length. For large n the geometric tail could be exploited. That is, with reasonable large n the complete distribution is characterized. The algorithm is based on Waldmann's survival function iteration procedure. For varying limits and for change points after 1 the algorithm from Knoth (2004) is applied. Note that for one-sided EWMA charts (`sided="one"`), only `"vac1"` and `"stat"` are deployed, while for two-sided ones (`sided="two"`) also `"fir"`, `"both"` (combination of `"fir"` and `"vac1"`), and `"Steiner"` are implemented. For details see Knoth (2004).

Value

Returns a vector which resembles the survival function up to a certain point.

Author(s)

Sven Knoth

References

- F. F. Gan (1993), An optimal design of EWMA control charts based on the median run length, *J. Stat. Comput. Simulation* 45, 169-184.
- S. Knoth (2003), EWMA schemes with non-homogeneous transition kernels, *Sequential Analysis* 22, 241-255.
- S. Knoth (2004), Fast initial response features for EWMA Control Charts, *Statistical Papers* 46, 47-64.
- K.-H. Waldmann (1986), Bounds for the distribution of the run length of geometric moving average charts, *Appl. Statist.* 35, 151-158.

See Also

`xewma.ar1` for zero-state ARL computation of EWMA control charts.

Examples

```
## Gan (1993), two-sided EWMA with fixed control limits
## some values of his Table 1 -- any median RL should be 500

G.lambda <- c(.05, .1, .15, .2, .25)
G.h <- c(.441, .675, .863, 1.027, 1.177)/sqrt(G.lambda/(2-G.lambda))

for ( i in 1:length(G.lambda) ) {
  SF <- xewma.sf(G.lambda[i], G.h[i], 0, 1000)
  if (i==1) plot(1:length(SF), SF, type="l", xlab="n", ylab="P(L>n)")
  else lines(1:length(SF), SF, col=i)
}
```

xewma.sf.prerun	<i>Compute the survival function of EWMA run length in case of estimated parameters</i>
-----------------	---

Description

Computation of the survival function of the Run Length (RL) for EWMA control charts monitoring normal mean if the in-control mean, standard deviation, or both are estimated by a pre run.

Usage

```
xewma.sf.prerun(l, c, mu, n, zr=0, hs=0, sided="one", limits="fix", q=1,
size=100, df=NULL, estimated="mu", qm.mu=30, qm.sigma=30,
truncate=1e-10, tail_approx=TRUE, bound=1e-10)
```

Arguments

l	smoothing parameter lambda of the EWMA control chart.
c	critical value (similar to alarm limit) of the EWMA control chart.
mu	true mean.
n	calculate sf up to value n.
zr	reflection border for the one-sided chart.
hs	so-called headstart (give fast initial response).
sided	distinguish between one- and two-sided EWMA control chart by choosing "one" and "two", respectively.
limits	distinguish between different control limits behavior.
q	change point position. For $q = 1$ and $\mu = \mu_0$ and $\mu = \mu_1$, the usual zero-state situation for the in-control and out-of-control case, respectively, are calculated. Note that $\mu_0=0$ is implicitly fixed.
size	pre run sample size.
df	degrees of freedom of the pre run variance estimator. Typically it is simply size - 1. If the pre run is collected in batches, then also other values are needed.
estimated	name the parameter to be estimated within the "mu", "sigma", "both".
qm.mu	number of quadrature nodes for convoluting the mean uncertainty.
qm.sigma	number of quadrature nodes for convoluting the standard deviation uncertainty.
truncate	size of truncated tail.
tail_approx	Controls whether the geometric tail approximation is used (is faster) or not.
bound	control when the geometric tail kicks in; the larger the quicker and less accurate; bound should be larger than 0 and less than 0.001.

Details

The survival function $P(L>n)$ and derived from it also the cdf $P(L\leq n)$ and the pmf $P(L=n)$ illustrate the distribution of the EWMA run length...

Value

Returns a vector which resembles the survival function up to a certain point.

Author(s)

Sven Knoth

References

- F. F. Gan (1993), An optimal design of EWMA control charts based on the median run length, *J. Stat. Comput. Simulation* 45, 169-184.
- S. Knoth (2003), EWMA schemes with non-homogeneous transition kernels, *Sequential Analysis* 22, 241-255.
- S. Knoth (2004), Fast initial response features for EWMA Control Charts, *Statistical Papers* 46, 47-64.
- L. A. Jones, C. W. Champ, S. E. Rigdon (2001), The performance of exponentially weighted moving average charts with estimated parameters, *Technometrics* 43, 156-167.
- K.-H. Waldmann (1986), Bounds for the distribution of the run length of geometric moving average charts, *Appl. Statist.* 35, 151-158.

See Also

xewma.sf for the RL survival function of EWMA control charts w/o pre run uncertainty.

Examples

```
## Jones/Champ/Rigdon (2001)

c4m <- function(m, n) sqrt(2)*gamma( (m*(n-1)+1)/2 )/sqrt( m*(n-1) )/gamma( m*(n-1)/2 )

n <- 5 # sample size

# Figure 6, subfigure r=0.1
lambda <- 0.1
L <- 2.454

CDF0 <- 1 - xewma.sf(lambda, L, 0, 600, sided="two")
m <- 10 # pre run size
CDF1 <- 1 - xewma.sf.prerun(lambda, L/c4m(m,n), 0, 600, sided="two",
size=m, df=m*(n-1), estimated="both")
m <- 20
CDF2 <- 1 - xewma.sf.prerun(lambda, L/c4m(m,n), 0, 600, sided="two",
size=m, df=m*(n-1), estimated="both")
m <- 50
```

```

CDF3 <- 1 - xewma.sf.prerun(lambda, L/c4m(m,n), 0, 600, sided="two",
size=m, df=m*(n-1), estimated="both")

plot(CDF0, type="l", xlab="t", ylab=expression(P(T<=t)), xlim=c(0,500), ylim=c(0,1))
abline(v=0, h=c(0,1), col="grey", lwd=.7)
points((1:5)*100, CDF0[(1:5)*100], pch=18)
lines(CDF1, col="blue")
points((1:5)*100, CDF1[(1:5)*100], pch=2, col="blue")
lines(CDF2, col="red")
points((1:5)*100, CDF2[(1:5)*100], pch=16, col="red")
lines(CDF3, col="green")
points((1:5)*100, CDF3[(1:5)*100], pch=5, col="green")

legend("bottomright", c("Known", "m=10, n=5", "m=20, n=5", "m=50, n=5"),
      col=c("black", "blue", "red", "green"), pch=c(18, 2, 16, 5), lty=1)

```

xgrsr.ad

Compute steady-state ARLs of Shiryaev-Roberts schemes

Description

Computation of the steady-state Average Run Length (ARL) for Shiryaev-Roberts schemes monitoring normal mean.

Usage

```
xgrsr.ad(k, g, mu1, mu0 = 0, zr = 0, sided = "one", MPT = FALSE, r = 30)
```

Arguments

k	reference value of the Shiryaev-Roberts scheme.
g	control limit (alarm threshold) of Shiryaev-Roberts scheme.
mu1	out-of-control mean.
mu0	in-control mean.
zr	reflection border to enable the numerical algorithms used here.
sided	distinguishes between one- and two-sided schemes by choosing "one" and "two", respectively. Currently only one-sided schemes are implemented.
MPT	switch between the old implementation (FALSE) and the new one (TRUE) that considers the completed likelihood ratio. MPT contains the initials of G. Moustakides, A. Polunchenko and A. Tartakovsky.
r	number of quadrature nodes, dimension of the resulting linear equation system is equal to r+1.

Details

xgrsr.ad determines the steady-state Average Run Length (ARL) by numerically solving the related ARL integral equation by means of the Nystroem method based on Gauss-Legendre quadrature.

Value

Returns a single value which resembles the steady-state ARL.

Author(s)

Sven Knoth

References

S. Knoth (2006), The art of evaluating monitoring schemes – how to measure the performance of control charts? S. Lenz, H. & Wilrich, P. (ed.), *Frontiers in Statistical Quality Control 8*, Physica Verlag, Heidelberg, Germany, 74-99.

G. Moustakides, A. Polunchenko, A. Tartakovsky (2009), Numerical comparison of CUSUM and Shiryaev-Roberts procedures for detecting changes in distributions, *Communications in Statistics: Theory and Methods 38*, 3225-3239.

See Also

xewma.arl and xcusum-arl for zero-state ARL computation of EWMA and CUSUM control charts, respectively, and xgrsr.arl for the zero-state ARL.

Examples

```
## Small study to identify appropriate reflection border to mimic unreflected schemes
k <- .5
g <- log(390)
zrs <- -(0:10)
ZRxgrsr.ad <- Vectorize(xgrsr.ad, "zr")
ads <- ZRxgrsr.ad(k, g, 0, zr=zrs)
data.frame(zrs, ads)
```

```
## Table 2 from Knoth (2006)
## original values are
# mu arl
# 0 689
# 0.5 30
# 1 8.9
# 1.5 5.1
# 2 3.6
# 2.5 2.8
# 3 2.4
#
k <- .5
g <- log(390)
zr <- -5 # see first example
mus <- (0:6)/2
Mxgrsr.ad <- Vectorize(xgrsr.ad, "mu1")
ads <- round(Mxgrsr.ad(k, g, mus, zr=zr), digits=1)
data.frame(mus, ads)
```

```
## Table 4 from Moustakides et al. (2009)
```

```
## original values are
# gamma A      STADD/steady-state ARL
# 50      28.02  4.37
# 100     56.04  5.46
# 500     280.19 8.33
# 1000    560.37 9.64
# 5000    2801.75 12.79
# 10000   5603.7 14.17
Gxgrsr.ad <- Vectorize("xgrsr.ad", "g")
As <- c(28.02, 56.04, 280.19, 560.37, 2801.75, 5603.7)
gs <- log(As)
theta <- 1
zr <- -6
ads <- round(Gxgrsr.ad(theta/2, gs, theta, zr=zr, r=100), digits=2)
data.frame(As, ads)
```

xgrsr.arl

Compute (zero-state) ARLs of Shiryayev-Roberts schemes

Description

Computation of the (zero-state) Average Run Length (ARL) for Shiryayev-Roberts schemes monitoring normal mean.

Usage

```
xgrsr.arl(k, g, mu, zr = 0, hs=NULL, sided = "one", q = 1, MPT = FALSE, r = 30)
```

Arguments

k	reference value of the Shiryayev-Roberts scheme.
g	control limit (alarm threshold) of Shiryayev-Roberts scheme.
mu	true mean.
zr	reflection border to enable the numerical algorithms used here.
hs	so-called headstart (enables fast initial response). If hs=NULL, then the classical headstart -Inf is used (corresponds to 0 for the non-log scheme).
sided	distinguishes between one- and two-sided schemes by choosing "one" and "two", respectively. Currently only one-sided schemes are implemented.
q	change point position. For $q = 1$ and $\mu = \mu_0$ and $\mu = \mu_1$, the usual zero-state ARLs for the in-control and out-of-control case, respectively, are calculated. For $q > 1$ and $\mu^! = 0$ conditional delays, that is, $E_q(L - q + 1 L \geq q)$, will be determined. Note that $\mu_0=0$ is implicitly fixed.
MPT	switch between the old implementation (FALSE) and the new one (TRUE) that considers the complete likelihood ratio. MPT stands for the initials of G. Moustakides, A. Polunchenko and A. Tartakovsky.
r	number of quadrature nodes, dimension of the resulting linear equation system is equal to r+1.

Details

xgrsr.arl determines the Average Run Length (ARL) by numerically solving the related ARL integral equation by means of the Nystroem method based on Gauss-Legendre quadrature.

Value

Returns a vector of length q which resembles the ARL and the sequence of conditional expected delays for q=1 and q>1, respectively.

Author(s)

Sven Knoth

References

S. Knoth (2006), The art of evaluating monitoring schemes – how to measure the performance of control charts? S. Lenz, H. & Wilrich, P. (ed.), *Frontiers in Statistical Quality Control 8*, Physica Verlag, Heidelberg, Germany, 74-99.

G. Moustakides, A. Polunchenko, A. Tartakovsky (2009), Numerical comparison of CUSUM and Shiryaev-Roberts procedures for detecting changes in distributions, *Communications in Statistics: Theory and Methods 38*, 3225-3239.

See Also

xewma.arl and xcusum-arl for zero-state ARL computation of EWMA and CUSUM control charts, respectively, and xgrsr.ad for the steady-state ARL.

Examples

```
## Small study to identify appropriate reflection border to mimic unreflected schemes
k <- .5
g <- log(390)
zrs <- -(0:10)
ZRxgrsr.arl <- Vectorize(xgrsr.arl, "zr")
arls <- ZRxgrsr.arl(k, g, 0, zr=zrs)
data.frame(zrs, arls)

## Table 2 from Knoth (2006)
## original values are
# mu arl
# 0 697
# 0.5 33
# 1 10.4
# 1.5 6.2
# 2 4.4
# 2.5 3.5
# 3 2.9
#
k <- .5
g <- log(390)
```

```

zr <- -5 # see first example
mus <- (0:6)/2
Mxgrsr.arl <- Vectorize(xgrsr.arl, "mu")
arls <- round(Mxgrsr.arl(k, g, mus, zr=zr), digits=1)
data.frame(mus, arls)

XGRSR.arl <- Vectorize("xgrsr.arl", "g")
zr <- -6

## Table 2 from Moustakides et al. (2009)
## original values are
# gamma  A      ARL/E_infty(L) SADD/E_1(L)
# 50    47.17      50.29      41.40
# 100   94.34     100.28      72.32
# 500  471.70     500.28     209.44
# 1000 943.41    1000.28     298.50
# 5000 4717.04   5000.24     557.87
#10000 9434.08  10000.17    684.17

theta <- .1
As2 <- c(47.17, 94.34, 471.7, 943.41, 4717.04, 9434.08)
gs2 <- log(As2)
arls0 <- round(XGRSR.arl(theta/2, gs2, 0, zr=-5, r=300, MPT=TRUE), digits=2)
arls1 <- round(XGRSR.arl(theta/2, gs2, theta, zr=-5, r=300, MPT=TRUE), digits=2)
data.frame(As2, arls0, arls1)

## Table 3 from Moustakides et al. (2009)
## original values are
# gamma  A      ARL/E_infty(L) SADD/E_1(L)
# 50    37.38      49.45      12.30
# 100   74.76      99.45      16.60
# 500  373.81     499.45     28.05
# 1000 747.62     999.45     33.33
# 5000 3738.08   4999.45     45.96
#10000 7476.15   9999.24     51.49

theta <- .5
As3 <- c(37.38, 74.76, 373.81, 747.62, 3738.08, 7476.15)
gs3 <- log(As3)
arls0 <- round(XGRSR.arl(theta/2, gs3, 0, zr=-5, r=70, MPT=TRUE), digits=2)
arls1 <- round(XGRSR.arl(theta/2, gs3, theta, zr=-5, r=70, MPT=TRUE), digits=2)
data.frame(As3, arls0, arls1)

## Table 4 from Moustakides et al. (2009)
## original values are
# gamma  A      ARL/E_infty(L) SADD/E_1(L)
# 50    28.02      49.78       4.98
# 100   56.04      99.79       6.22
# 500  280.19     499.79      9.30
# 1000 560.37     999.79     10.66
# 5000 2801.85   5000.93     13.86
#10000 5603.70   9999.87     15.24

```

```
theta <- 1
As4 <- c(28.02, 56.04, 280.19, 560.37, 2801.85, 5603.7)
gs4 <- log(As4)
arls0 <- round(XGRSR.arl(theta/2, gs4, 0, zr=-6, r=40, MPT=TRUE), digits=2)
arls1 <- round(XGRSR.arl(theta/2, gs4, theta, zr=-6, r=40, MPT=TRUE), digits=2)
data.frame(As4, arls0, arls1)
```

xgrsr.crit

Compute alarm thresholds for Shiryaev-Roberts schemes

Description

Computation of the alarm thresholds (alarm limits) for Shiryaev-Roberts schemes monitoring normal mean.

Usage

```
xgrsr.crit(k, L0, mu0 = 0, zr = 0, hs = NULL, sided = "one", MPT = FALSE, r = 30)
```

Arguments

k	reference value of the Shiryaev-Roberts scheme.
L0	in-control ARL.
mu0	in-control mean.
zr	reflection border to enable the numerical algorithms used here.
hs	so-called headstart (enables fast initial response). If hs=NULL, then the classical headstart -Inf is used (corresponds to 0 for the non-log scheme).
sided	distinguishes between one- and two-sided schemes by choosing "one" and "two", respectively. Currently only one-sided schemes are implemented.
MPT	switch between the old implementation (FALSE) and the new one (TRUE) that considers the completed likelihood ratio. MPT contains the initials of G. Moustakides, A. Polunchenko and A. Tartakovsky.
r	number of quadrature nodes, dimension of the resulting linear equation system is equal to r+1.

Details

xgrsr.crit determines the alarm threshold (alarm limit) for given in-control ARL L0 by applying secant rule and using xgrsr.arl().

Value

Returns a single value which resembles the alarm limit g.

Author(s)

Sven Knoth

References

G. Moustakides, A. Polunchenko, A. Tartakovsky (2009), Numerical comparison of CUSUM and Shiryaev-Roberts procedures for detecting changes in distributions, *Communications in Statistics: Theory and Methods* 38, 3225-3239.r.

See Also

xgrsr.arl for zero-state ARL computation.

Examples

```
## Table 4 from Moustakides et al. (2009)
## original values are
# gamma/L0 A/exp(g)
# 50      28.02
# 100     56.04
# 500     280.19
# 1000    560.37
# 5000    2801.75
# 10000   5603.7
theta <- 1
zr <- -6
r <- 100
Lxgrsr.crit <- Vectorize("xgrsr.crit", "L0")
L0s <- c(50, 100, 500, 1000, 5000, 10000)
gs <- Lxgrsr.crit(theta/2, L0s, zr=zr, r=r)
data.frame(L0s, gs, A=round(exp(gs), digits=2))
```

xsewma.arl

Compute ARLs of simultaneous EWMA control charts (mean and variance charts)

Description

Computation of the (zero-state) Average Run Length (ARL) for different types of simultaneous EWMA control charts (based on the sample mean and the sample variance S^2) monitoring normal mean and variance.

Usage

```
xsewma.arl(lx, cx, ls, csu, df, mu, sigma, hsx=0, Nx=40, csl=0,
hss=1, Ns=40, s2.on=TRUE, sided="upper", qm=30)
```

Arguments

lx smoothing parameter lambda of the two-sided mean EWMA chart.
cx control limit of the two-sided mean EWMA control chart.
ls smoothing parameter lambda of the variance EWMA chart.

csu	upper control limit of the variance EWMA control chart.
df	actual degrees of freedom, corresponds to subgroup size (for known mean it is equal to the subgroup size, for unknown mean it is equal to subgroup size minus one).
mu	true mean.
sigma	true standard deviation.
hsx	so-called headstart (enables fast initial response) of the mean chart – do not confuse with the true FIR feature considered in xewma.ar1; will be updated.
Nx	dimension of the approximating matrix of the mean chart.
cs1	lower control limit of the variance EWMA control chart; default value is 0; not considered if sided is "upper".
hss	headstart (enables fast initial response) of the variance chart.
Ns	dimension of the approximating matrix of the variance chart.
s2.on	distinguishes between S^2 and S chart.
sided	distinguishes between one- and two-sided two-sided EWMA- S^2 control charts by choosing "upper" (upper chart without reflection at c1 – the actual value of c1 is not used), "Rupper" (upper chart with reflection at c1), "Rlower" (lower chart with reflection at cu), and "two" (two-sided chart), respectively.
qm	number of quadrature nodes used for the collocation integrals.

Details

xsewma.ar1 determines the Average Run Length (ARL) by an extension of Gan's (derived from ideas already published by Waldmann) algorithm. The variance EWMA part is treated similarly to the ARL calculation method deployed for the single variance EWMA charts in Knoth (2005), that is, by means of collocation (Chebyshev polynomials). For more details see Knoth (2007).

Value

Returns a single value which resembles the ARL.

Author(s)

Sven Knoth

References

- K. Waldmann (1986), Bounds for the distribution of the run length of geometric moving average charts, *J. R. Stat. Soc., Ser. C, Appl. Stat.* 35, 151-158.
- F. F. Gan (1995), Joint monitoring of process mean and variance using exponentially weighted moving average control charts, *Technometrics* 37, 446-453.
- S. Knoth (2005), Accurate ARL computation for EWMA- S^2 control charts, *Statistics and Computing* 15, 341-352.
- S. Knoth (2007), Accurate ARL calculation for EWMA control charts monitoring simultaneously normal mean and variance, *Sequential Analysis* 26, 251-264.

See Also

xewma.arl and sewma.arl for zero-state ARL computation of single mean and variance EWMA control charts, respectively.

Examples

```
## Knoth (2007)
## collocation results in Table 1
## Monte Carlo with 10^9 replicates: 252.307 +/- 0.0078

# process parameters
mu <- 0
sigma <- 1
# subgroup size n=5, df=n-1
df <- 4
# lambda of mean chart
lx <- .134
# c_mu^* = .345476571 = cx/sqrt(n) * sqrt(lx/(2-lx))
cx <- .345476571*sqrt(df+1)/sqrt(lx/(2-lx))
# lambda of variance chart
ls <- .1
# c_sigma = .477977
csu <- 1 + .477977
# matrix dimensions for mean and variance part
Nx <- 25
Ns <- 25
# mode of variance chart
SIDED <- "upper"

arl <- xsewma.arl(lx, cx, ls, csu, df, mu, sigma, Nx=Nx, Ns=Ns, sided=SIDED)
arl
```

xsewma.crit

Compute critical values of simultaneous EWMA control charts (mean and variance charts)

Description

Computation of the critical values (similar to alarm limits) for different types of simultaneous EWMA control charts (based on the sample mean and the sample variance S^2) monitoring normal mean and variance.

Usage

```
xsewma.crit(lx, ls, L0, df, mu0=0, sigma0=1, cu=NULL, hsx=0,
hss=1, s2.on=TRUE, sided="upper", mode="fixed", Nx=30, Ns=40, qm=30)
```

Arguments

lx	smoothing parameter lambda of the two-sided mean EWMA chart.
ls	smoothing parameter lambda of the variance EWMA chart.
L0	in-control ARL.
mu0	in-control mean.
sigma0	in-control standard deviation.
cu	for two-sided (sided="two") and fixed upper control limit (mode="fixed") a value larger than sigma0 has to been given, for all other cases cu is ignored.
hsx	so-called headstart (enables fast initial response) of the mean chart – do not confuse with the true FIR feature considered in xewma.arl; will be updated.
hss	headstart (enables fast initial response) of the variance chart.
df	actual degrees of freedom, corresponds to subgroup size (for known mean it is equal to the subgroup size, for unknown mean it is equal to subgroup size minus one).
s2.on	distinguishes between S^2 and S chart.
sided	distinguishes between one- and two-sided two-sided EWMA- S^2 control charts by choosing "upper" (upper chart without reflection at c1 – the actual value of c1 is not used), "Rupper" (upper chart with reflection at c1), "Rlower" (lower chart with reflection at cu), and "two" (two-sided chart), respectively.
mode	only deployed for sided="two" – with "fixed" an upper control limit (see cu) is set and only the lower is determined to obtain the in-control ARL L0, while with "unbiased" a certain unbiasedness of the ARL function is guaranteed (here, both the lower and the upper control limit are calculated).
Nx	dimension of the approximating matrix of the mean chart.
Ns	dimension of the approximating matrix of the variance chart.
qm	number of quadrature nodes used for the collocation integrals.

Details

xsewma.crit determines the critical values (similar to alarm limits) for given in-control ARL L0 by applying secant rule and using xsewma.arl(). In case of sided="two" and mode="unbiased" a two-dimensional secant rule is applied that also ensures that the maximum of the ARL function for given standard deviation is attained at sigma0. See Knoth (2007) for details and application.

Value

Returns the critical value of the two-sided mean EWMA chart and the lower and upper controls limit c1 and cu of the variance EWMA chart.

Author(s)

Sven Knoth

References

S. Knoth (2007), Accurate ARL calculation for EWMA control charts monitoring simultaneously normal mean and variance, *Sequential Analysis* 26, 251-264.

See Also

xsewma.arl for calculation of ARL of simultaneous EWMA charts.

Examples

```
## Knoth (2007)
## results in Table 2

# subgroup size n=5, df=n-1
df <- 4
# lambda of mean chart
lx <- .134
# lambda of variance chart
ls <- .1
# in-control ARL
L0 <- 252.3
# matrix dimensions for mean and variance part
Nx <- 25
Ns <- 25
# mode of variance chart
SIDED <- "upper"

crit <- xsewma.crit(lx, ls, L0, df, sided=SIDED, Nx=Nx, Ns=Ns)
crit

## output as used in Knoth (2007)
crit["cx"]/sqrt(df+1)*sqrt(lx/(2-lx))
crit["cu"] - 1
```

xsewma.q

Compute critical values of simultaneous EWMA control charts (mean and variance charts) for given RL quantile

Description

Computation of the critical values (similar to alarm limits) for different types of simultaneous EWMA control charts (based on the sample mean and the sample variance S^2) monitoring normal mean and variance.

Usage

```
xsewma.q(lx, cx, ls, csu, df, alpha, mu, sigma, hsx=0,
Nx=40, csl=0, hss=1, Ns=40, sided="upper", qm=30)
```

```
xsewma.q.crit(lx, ls, L0, alpha, df, mu0=0, sigma0=1, csu=NULL,
hsx=0, hss=1, sided="upper", mode="fixed", Nx=20, Ns=40, qm=30,
c.error=1e-12, a.error=1e-9)
```

Arguments

lx	smoothing parameter lambda of the two-sided mean EWMA chart.
cx	control limit of the two-sided mean EWMA control chart.
ls	smoothing parameter lambda of the variance EWMA chart.
csu	for two-sided (sided="two") and fixed upper control limit (mode="fixed", only for xsewma.q.crit) a value larger than sigma0 has to been given, for all other cases cu is ignored. It is the upper control limit of the variance EWMA control chart.
L0	in-control RL quantile at level alpha.
df	actual degrees of freedom, corresponds to subgroup size (for known mean it is equal to the subgroup size, for unknown mean it is equal to subgroup size minus one).
alpha	quantile level.
mu	true mean.
sigma	true standard deviation.
mu0	in-control mean.
sigma0	in-control standard deviation.
hsx	so-called headstart (enables fast initial response) of the mean chart – do not confuse with the true FIR feature considered in xewma.arl; will be updated.
Nx	dimension of the approximating matrix of the mean chart.
csl	lower control limit of the variance EWMA control chart; default value is 0; not considered if sided is "upper".
hss	headstart (enables fast initial response) of the variance chart.
Ns	dimension of the approximating matrix of the variance chart.
sided	distinguishes between one- and two-sided two-sided EWMA- S^2 control charts by choosing "upper" (upper chart without reflection at c1 – the actual value of of c1 is not used).
mode	only deployed for sided="two" – with "fixed" an upper control limit (see cu) is set and only the lower is determined to obtain the in-control ARL L0, while with "unbiased" a certain unbiasedness of the ARL function is guaranteed (here, both the lower and the upper control limit are calculated).
qm	number of quadrature nodes used for the collocation integrals.
c.error	error bound for two succeeding values of the critical value during applying the secant rule.
a.error	error bound for the quantile level alpha during applying the secant rule.

Details

Instead of the popular ARL (Average Run Length) quantiles of the EWMA stopping time (Run Length) are determined. The algorithm is based on Waldmann's survival function iteration procedure and on Knoth (2007). `xsewma.q.crit` determines the critical values (similar to alarm limits) for given in-control RL quantile L_0 at level α by applying secant rule and using `xsewma.sf()`. In case of `sided="two"` and `mode="unbiased"` a two-dimensional secant rule is applied that also ensures that the maximum of the RL cdf for given standard deviation is attained at σ_0 .

Value

Returns a single value which resembles the RL quantile of order α and the critical value of the two-sided mean EWMA chart and the lower and upper controls limit `csl` and `csu` of the variance EWMA chart, respectively.

Author(s)

Sven Knoth

References

S. Knoth (2007), Accurate ARL calculation for EWMA control charts monitoring simultaneously normal mean and variance, *Sequential Analysis* 26, 251-264.

See Also

`xsewma.arl` for calculation of ARL of simultaneous EWMA charts and `xsewma.sf` for the RL survival function.

Examples

```
## Knoth (2014?)
```

<code>xsewma.sf</code>	<i>Compute the survival function of simultaneous EWMA control charts (mean and variance charts)</i>
------------------------	---

Description

Computation of the survival function of the Run Length (RL) for EWMA control charts monitoring simultaneously normal mean and variance.

Usage

```
xsewma.sf(n, lx, cx, ls, csu, df, mu, sigma, hsx=0, Nx=40,
          csl=0, hss=1, Ns=40, sided="upper", qm=30)
```

Arguments

n	calculate sf up to value n.
lx	smoothing parameter lambda of the two-sided mean EWMA chart.
cx	control limit of the two-sided mean EWMA control chart.
ls	smoothing parameter lambda of the variance EWMA chart.
csu	upper control limit of the variance EWMA control chart.
df	actual degrees of freedom, corresponds to subgroup size (for known mean it is equal to the subgroup size, for unknown mean it is equal to subgroup size minus one).
mu	true mean.
sigma	true standard deviation.
hsx	so-called headstart (enables fast initial response) of the mean chart – do not confuse with the true FIR feature considered in xewma.arl; will be updated.
Nx	dimension of the approximating matrix of the mean chart.
cs1	lower control limit of the variance EWMA control chart; default value is 0; not considered if sided is "upper".
hss	headstart (enables fast initial response) of the variance chart.
Ns	dimension of the approximating matrix of the variance chart.
sided	distinguishes between one- and two-sided two-sided EWMA- S^2 control charts by choosing "upper" (upper chart without reflection at c1 – the actual value of c1 is not used), "Rupper" (upper chart with reflection at c1), "Rlower" (lower chart with reflection at cu), and "two" (two-sided chart), respectively.
qm	number of quadrature nodes used for the collocation integrals.

Details

The survival function $P(L>n)$ and derived from it also the cdf $P(L\leq n)$ and the pmf $P(L=n)$ illustrate the distribution of the EWMA run length. For large n the geometric tail could be exploited. That is, with reasonable large n the complete distribution is characterized. The algorithm is based on Waldmann's survival function iteration procedure and on results in Knoth (2007).

Value

Returns a vector which resembles the survival function up to a certain point.

Author(s)

Sven Knoth

References

- S. Knoth (2007), Accurate ARL calculation for EWMA control charts monitoring simultaneously normal mean and variance, *Sequential Analysis* 26, 251-264.
- K.-H. Waldmann (1986), Bounds for the distribution of the run length of geometric moving average charts, *Appl. Statist.* 35, 151-158.

See Also

xsewma.ar1 for zero-state ARL computation of simultaneous EWMA control charts.

Examples

```
## Knoth (2014?)
```

xshewhart.ar1.ar1 *Compute ARLs of modified Shewhart control charts for AR(1) data*

Description

Computation of the (zero-state) Average Run Length (ARL) for modified Shewhart charts deployed to the original AR(1) data.

Usage

```
xshewhart.ar1.ar1(alpha, cS, delta=0, N1=50, N2=30)
```

Arguments

alpha	lag 1 correlation of the data.
cS	critical value (alias to alarm limit) of the Shewhart control chart.
delta	potential shift in the data (in-control mean is zero).
N1	number of quadrature nodes for solving the ARL integral equation, dimension of the resulting linear equation system is N1.
N2	second number of quadrature nodes for combining the probability density function of the first observation following the margin distribution and the solution of the ARL integral equation.

Details

Following the idea of Schmid (1995), $1 - \alpha$ times the data turns out to be an EWMA smoothing of the underlying AR(1) residuals. Hence, by combining the solution of the EWMA ARL integral equation and the stationary distribution of the AR(1) data (normal distribution is assumed) one gets easily the overall ARL.

Value

It returns a single value resembling the zero-state ARL of a modified Shewhart chart.

Author(s)

Sven Knoth

References

- S. Knoth, W. Schmid (2004). Control charts for time series: A review. In *Frontiers in Statistical Quality Control 7*, edited by H.-J. Lenz, P.-T. Wilrich, 210-236, Physica-Verlag.
- H. Kramer, W. Schmid (2000). The influence of parameter estimation on the ARL of Shewhart type charts for time series. *Statistical Papers 41*(2), 173-196.
- W. Schmid (1995). On the run length of a Shewhart chart for correlated data. *Statistical Papers 36*(1), 111-130.

See Also

xewma.arl for zero-state ARL computation of EWMA control charts.

Examples

```
## Table 1 in Kramer/Schmid (2000)

cS <- 3.09023
a <- seq(0, 4, by=.5)
row1 <- row2 <- row3 <- NULL
for ( i in 1:length(a) ) {
  row1 <- c(row1, round(xshewhart.arl.arl( 0.4, cS, delta=a[i]), digits=2))
  row2 <- c(row2, round(xshewhart.arl.arl( 0.2, cS, delta=a[i]), digits=2))
  row3 <- c(row3, round(xshewhart.arl.arl(-0.2, cS, delta=a[i]), digits=2))
}

results <- rbind(row1, row2, row3)
results

# original values are
# row1 515.44 215.48 61.85 21.63 9.19 4.58 2.61 1.71 1.29
# row2 502.56 204.97 56.72 19.13 7.95 3.97 2.33 1.59 1.25
# row3 502.56 201.41 54.05 17.42 6.89 3.37 2.03 1.46 1.20
```

xshewhartrunsrules.arl

Compute ARLs of Shewhart control charts with and without runs rules

Description

Computation of the (zero-state and steady-state) Average Run Length (ARL) for Shewhart control charts with and without runs rules monitoring normal mean.

Usage

```
xshewhartrunsrules.arl(mu, c = 1, type = "12")

xshewhartrunsrules.crit(L0, mu = 0, type = "12")
```

```
xshewhartrunrules.ad(mu1, mu0 = 0, c = 1, type = "12")
```

```
xshewhartrunrules.matrix(mu, c = 1, type = "12")
```

Arguments

mu	true mean.
L0	pre-defined in-control ARL, that is, determine c so that the mean number of observations until a false alarm is L0.
mu1, mu0	for the steady-state ARL two means are specified, mu0 is the in-control one and usually equal to 0, and mu1 must be given.
c	normalizing constant to ensure specific alarming behavior.
type	controls the type of Shewhart chart used, see details section.

Details

xshewhartrunrules.arl determines the zero-state Average Run Length (ARL) based on the Markov chain approach given in Champ and Woodall (1987). xshewhartrunrules.matrix provides the corresponding transition matrix that is also used in xDshewhartrunrules.arl (ARL for control charting drift). xshewhartrunrules.crit allows to find the normalization constant c to attain a fixed in-control ARL. Typically this is needed to calibrate the chart. With xshewhartrunrules.ad the steady-state ARL is calculated. With the argument type certain runs rules could be set. The following list gives an overview.

- "1" The classical Shewhart chart with $\pm 3 c \sigma$ control limits (c is typically equal to 1 and can be changed by the argument c).
- "12" The classic and the following runs rule: 2 of 3 are beyond $\pm 2 c \sigma$ on the same side of the chart.
- "13" The classic and the following runs rule: 4 of 5 are beyond $\pm 1 c \sigma$ on the same side of the chart.
- "14" The classic and the following runs rule: 8 of 8 are on the same side of the chart (referring to the center line).

Value

Returns a single value which resembles the zero-state or steady-state ARL. xshewhartrunrules.matrix returns a matrix.

Author(s)

Sven Knoth

References

C. W. Champ and W. H. Woodall (1987), Exact results for Shewhart control charts with supplementary runs rules, *Technometrics* 29, 393-399.

See Also

xDshewhartrunrules.arl for zero-state ARL of Shewhart control charts with or without runs rules under drift.

Examples

```
## Champ/Woodall (1987)
## Table 1
mus <- (0:15)/5
Mxshewhartrunrules.arl <- Vectorize(xshewhartrunrules.arl, "mu")
# standard (1 of 1 beyond 3 sigma) Shewhart chart without runs rules
C1 <- round(Mxshewhartrunrules.arl(mus, type="1"), digits=2)
# standard + runs rule: 2 of 3 beyond 2 sigma on the same side
C12 <- round(Mxshewhartrunrules.arl(mus, type="12"), digits=2)
# standard + runs rule: 4 of 5 beyond 1 sigma on the same side
C13 <- round(Mxshewhartrunrules.arl(mus, type="13"), digits=2)
# standard + runs rule: 8 of 8 on the same side of the center line
C14 <- round(Mxshewhartrunrules.arl(mus, type="14"), digits=2)

## original results are
# mus      C1      C12     C13     C14
# 0.0 370.40 225.44 166.05 152.73
# 0.2 308.43 177.56 120.70 110.52
# 0.4 200.08 104.46  63.88  59.76
# 0.6 119.67  57.92  33.99  33.64
# 0.8  71.55  33.12  19.78  21.07
# 1.0  43.89  20.01  12.66  14.58
# 1.2  27.82  12.81   8.84  10.90
# 1.4  18.25   8.69   6.62   8.60
# 1.6  12.38   6.21   5.24   7.03
# 1.8   8.69   4.66   4.33   5.85
# 2.0   6.30   3.65   3.68   4.89
# 2.2   4.72   2.96   3.18   4.08
# 2.4   3.65   2.48   2.78   3.38
# 2.6   2.90   2.13   2.43   2.81
# 2.8   2.38   1.87   2.14   2.35
# 3.0   2.00   1.68   1.89   1.99

data.frame(mus, C1, C12, C13, C14)

## plus calibration, i. e. L0=250 (the maximal value for "14" is 255!
L0 <- 250
c1 <- xshewhartrunrules.crit(L0, type = "1")
c12 <- xshewhartrunrules.crit(L0, type = "12")
c13 <- xshewhartrunrules.crit(L0, type = "13")
c14 <- xshewhartrunrules.crit(L0, type = "14")
C1 <- round(Mxshewhartrunrules.arl(mus, c=c1, type="1"), digits=2)
C12 <- round(Mxshewhartrunrules.arl(mus, c=c12, type="12"), digits=2)
C13 <- round(Mxshewhartrunrules.arl(mus, c=c13, type="13"), digits=2)
C14 <- round(Mxshewhartrunrules.arl(mus, c=c14, type="14"), digits=2)
data.frame(mus, C1, C12, C13, C14)
```

```
## and the steady-state ARL
Mxshewhartrunrules.ad <- Vectorize(xshewhartrunrules.ad, "mu1")
C1 <- round(Mxshewhartrunrules.ad(mus, c=c1, type="1"), digits=2)
C12 <- round(Mxshewhartrunrules.ad(mus, c=c12, type="12"), digits=2)
C13 <- round(Mxshewhartrunrules.ad(mus, c=c13, type="13"), digits=2)
C14 <- round(Mxshewhartrunrules.ad(mus, c=c14, type="14"), digits=2)
data.frame(mus, C1, C12, C13, C14)
```

xtcusum.arl

Compute ARLs of CUSUM control charts

Description

Computation of the (zero-state) Average Run Length (ARL) for different types of CUSUM control charts monitoring normal mean.

Usage

```
xtcusum.arl(k, h, df, mu, hs = 0, sided="one", mode="tan", r=30)
```

Arguments

k	reference value of the CUSUM control chart.
h	decision interval (alarm limit, threshold) of the CUSUM control chart.
df	degrees of freedom – parameter of the t distribution.
mu	true mean.
hs	so-called headstart (give fast initial response).
sided	distinguish between one- and two-sided CUSUM schemes by choosing "one" and "two", respectively.
r	number of quadrature nodes, dimension of the resulting linear equation system is equal to r+1.
mode	Controls the type of variables substitution that might improve the numerical performance. Currently, "identity", "sin", "sinh", and "tan" (default) are provided.

Details

xtcusum.arl determines the Average Run Length (ARL) by numerically solving the related ARL integral equation by means of the Nystroem method based on Gauss-Legendre quadrature.

Value

Returns a single value which resembles the ARL.

Author(s)

Sven Knoth

References

- A. L. Goel, S. M. Wu (1971), Determination of A.R.L. and a contour nomogram for CUSUM charts to control normal mean, *Technometrics* 13, 221-230.
- D. Brook, D. A. Evans (1972), An approach to the probability distribution of cusum run length, *Biometrika* 59, 539-548.
- J. M. Lucas, R. B. Crosier (1982), Fast initial response for cusum quality-control schemes: Give your cusum a headstart, *Technometrics* 24, 199-205.
- L. C. Vance (1986), Average run lengths of cumulative sum control charts for controlling normal means, *Journal of Quality Technology* 18, 189-193.
- K.-H. Waldmann (1986), Bounds for the distribution of the run length of one-sided and two-sided CUSUM quality control schemes, *Technometrics* 28, 61-67.
- R. B. Crosier (1986), A new two-sided cumulative quality control scheme, *Technometrics* 28, 187-194.

See Also

xtewma.ar1 for zero-state ARL computation of EWMA control charts and xtcusum.ar1 for the zero-state ARL of CUSUM for normal data.

Examples

```
## will follow
```

```
xtewma.ad          Compute steady-state ARLs of EWMA control charts, t distributed data
```

Description

Computation of the steady-state Average Run Length (ARL) for different types of EWMA control charts monitoring the mean of t distributed data.

Usage

```
xtewma.ad(l, c, df, mu1, mu0=0, zr=0, z0=0, sided="one", limits="fix",
steady.state.mode="conditional", mode="tan", r=40)
```

Arguments

l	smoothing parameter lambda of the EWMA control chart.
c	critical value (similar to alarm limit) of the EWMA control chart.
df	degrees of freedom – parameter of the t distribution.
mu1	in-control mean.
mu0	out-of-control mean.
zr	reflection border for the one-sided chart.

z0	restarting value of the EWMA sequence in case of a false alarm in <code>steady.state.mode="cyclical"</code> .
sided	distinguishes between one- and two-sided two-sided EWMA control chart by choosing "one" and "two", respectively.
limits	distinguishes between different control limits behavior.
steady.state.mode	distinguishes between two steady-state modes – conditional and cyclical.
mode	Controls the type of variables substitution that might improve the numerical performance. Currently, "identity", "sin", "sinh", and "tan" (default) are provided.
r	number of quadrature nodes, dimension of the resulting linear equation system is equal to $r+1$ (one-sided) or r (two-sided).

Details

xtewma.ad determines the steady-state Average Run Length (ARL) by numerically solving the related ARL integral equation by means of the Nystroem method based on Gauss-Legendre quadrature and using the power method for deriving the largest in magnitude eigenvalue and the related left eigenfunction.

Value

Returns a single value which resembles the steady-state ARL.

Author(s)

Sven Knoth

References

- R. B. Crosier (1986), A new two-sided cumulative quality control scheme, *Technometrics* 28, 187-194.
- S. V. Crowder (1987), A simple method for studying run-length distributions of exponentially weighted moving average charts, *Technometrics* 29, 401-407.
- J. M. Lucas and M. S. Saccucci (1990), Exponentially weighted moving average control schemes: Properties and enhancements, *Technometrics* 32, 1-12.

See Also

xtewma.arl for zero-state ARL computation and xewma.ad for the steady-state ARL for normal data.

Examples

```
## will follow
```

 xtewma.arl

 Compute ARLs of EWMA control charts, t distributed data

Description

Computation of the (zero-state) Average Run Length (ARL) for different types of EWMA control charts monitoring the mean of t distributed data.

Usage

```
xtewma.arl(l,c,df,mu,zr=0,hs=0,sided="two",limits="fix",mode="tan",q=1,r=40)
```

Arguments

l	smoothing parameter lambda of the EWMA control chart.
c	critical value (similar to alarm limit) of the EWMA control chart.
df	degrees of freedom – parameter of the t distribution.
mu	true mean.
zr	reflection border for the one-sided chart.
hs	so-called headstart (enables fast initial response).
sided	distinguishes between one- and two-sided EWMA control chart by choosing "one" and "two", respectively.
limits	distinguishes between different control limits behavior.
mode	Controls the type of variables substitution that might improve the numerical performance. Currently, "identity", "sin", "sinh", and "tan" (default) are provided.
q	change point position. For $q = 1$ and $\mu = \mu_0$ and $\mu = \mu_1$, the usual zero-state ARLs for the in-control and out-of-control case, respectively, are calculated. For $q > 1$ and $\mu = 0$ conditional delays, that is, $E_q(L - q + 1 L \geq q)$, will be determined. Note that $\mu_0=0$ is implicitly fixed.
r	number of quadrature nodes, dimension of the resulting linear equation system is equal to $r+1$ (one-sided) or r (two-sided).

Details

In case of the EWMA chart with fixed control limits, `xtewma.arl` determines the Average Run Length (ARL) by numerically solving the related ARL integral equation by means of the Nystroem method based on Gauss-Legendre quadrature. If `limits` is "vacl", then the method presented in Knoth (2003) is utilized. Other values (normal case) for `limits` are not yet supported.

Value

Except for the fixed limits EWMA charts it returns a single value which resembles the ARL. For fixed limits charts, it returns a vector of length q which resembles the ARL and the sequence of conditional expected delays for $q=1$ and $q>1$, respectively.

Author(s)

Sven Knoth

References

K.-H. Waldmann (1986), Bounds for the distribution of the run length of geometric moving average charts, *Appl. Statist.* 35, 151-158.

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C. M. Borror, D. C. Montgomery, and G. C. Runger (1999), Robustness of the EWMA control chart to non-normality, *Journal of Quality Technology* 31, 309-316.

S. Knoth (2003), EWMA schemes with non-homogeneous transition kernels, *Sequential Analysis* 22, 241-255.

S. Knoth (2004), Fast initial response features for EWMA Control Charts, *Statistical Papers* 46, 47-64.

See Also

xewma.ar1 for zero-state ARL computation of EWMA control charts in the normal case.

Examples

```
## Borror/Montgomery/Runger (1999), Table 3
lambda <- 0.1
cE <- 2.703
df <- c(4, 6, 8, 10, 15, 20, 30, 40, 50)
L0 <- rep(NA, length(df))
for ( i in 1:length(df) ) {
  L0[i] <- round(xtewma.ar1(lambda, cE*sqrt(df[i]/(df[i]-2)), df[i], 0), digits=0)
}
data.frame(df, L0)
```

xtewma.q

Compute RL quantiles of EWMA control charts

Description

Computation of quantiles of the Run Length (RL) for EWMA control charts monitoring normal mean.

Usage

```
xtewma.q(l, c, df, mu, alpha, zr=0, hs=0, sided="two", limits="fix", mode="tan",
q=1, r=40)
```

```
xtewma.q.crit(l, L0, df, mu, alpha, zr=0, hs=0, sided="two", limits="fix", mode="tan",
r=40, c.error=1e-12, a.error=1e-9, OUTPUT=FALSE)
```

Arguments

l	smoothing parameter lambda of the EWMA control chart.
c	critical value (similar to alarm limit) of the EWMA control chart.
df	degrees of freedom – parameter of the t distribution.
mu	true mean.
alpha	quantile level.
zr	reflection border for the one-sided chart.
hs	so-called headstart (enables fast initial response).
sided	distinguishes between one- and two-sided EWMA control chart by choosing "one" and "two", respectively.
limits	distinguishes between different control limits behavior.
mode	Controls the type of variables substitution that might improve the numerical performance. Currently, "identity", "sin", "sinh", and "tan" (default) are provided.
q	change point position. For $q = 1$ and $\mu = \mu_0$ and $\mu = \mu_1$, the usual zero-state ARLs for the in-control and out-of-control case, respectively, are calculated. For $q > 1$ and $\mu = 0$ conditional delays, that is, $E_q(L - q + 1 L \geq)$, will be determined. Note that $\mu_0=0$ is implicitly fixed.
r	number of quadrature nodes, dimension of the resulting linear equation system is equal to $r+1$ (one-sided) or r (two-sided).
L0	in-control quantile value.
c.error	error bound for two succeeding values of the critical value during applying the secant rule.
a.error	error bound for the quantile level alpha during applying the secant rule.
OUTPUT	activate or deactivate additional output.

Details

Instead of the popular ARL (Average Run Length) quantiles of the EWMA stopping time (Run Length) are determined. The algorithm is based on Waldmann's survival function iteration procedure. If limits is "vac1", then the method presented in Knoth (2003) is utilized. For details see Knoth (2004).

Value

Returns a single value which resembles the RL quantile of order q.

Author(s)

Sven Knoth

References

F. F. Gan (1993), An optimal design of EWMA control charts based on the median run length, *J. Stat. Comput. Simulation* 45, 169-184.

S. Knoth (2003), EWMA schemes with non-homogeneous transition kernels, *Sequential Analysis* 22, 241-255.

S. Knoth (2004), Fast initial response features for EWMA Control Charts, *Statistical Papers* 46, 47-64.

K.-H. Waldmann (1986), Bounds for the distribution of the run length of geometric moving average charts, *Appl. Statist.* 35, 151-158.

See Also

xewma.q for RL quantile computation of EWMA control charts in the normal case.

Examples

```
## will follow
```

```
xtewma.sf
```

Compute the survival function of EWMA run length

Description

Computation of the survival function of the Run Length (RL) for EWMA control charts monitoring normal mean.

Usage

```
xtewma.sf(l, c, df, mu, n, zr=0, hs=0, sided="two", limits="fix", mode="tan", q=1, r=40)
```

Arguments

l	smoothing parameter lambda of the EWMA control chart.
c	critical value (similar to alarm limit) of the EWMA control chart.
df	degrees of freedom – parameter of the t distribution.
mu	true mean.
n	calculate sf up to value n.
zr	reflection border for the one-sided chart.
hs	so-called headstart (enables fast initial response).

sided	distinguishes between one- and two-sided EWMA control chart by choosing "one" and "two", respectively.
limits	distinguishes between different control limits behavior.
mode	Controls the type of variables substitution that might improve the numerical performance. Currently, "identity", "sin", "sinh", and "tan" (default) are provided.
q	change point position. For $q = 1$ and $\mu = \mu_0$ and $\mu = \mu_1$, the usual zero-state situation for the in-control and out-of-control case, respectively, are calculated. Note that $\mu_0=0$ is implicitly fixed.
r	number of quadrature nodes, dimension of the resulting linear equation system is equal to $r+1$ (one-sided) or r (two-sided).

Details

The survival function $P(L>n)$ and derived from it also the cdf $P(L\leq n)$ and the pmf $P(L=n)$ illustrate the distribution of the EWMA run length. For large n the geometric tail could be exploited. That is, with reasonable large n the complete distribution is characterized. The algorithm is based on Waldmann's survival function iteration procedure. For varying limits and for change points after 1 the algorithm from Knoth (2004) is applied. For details see Knoth (2004).

Value

Returns a vector which resembles the survival function up to a certain point.

Author(s)

Sven Knoth

References

- F. F. Gan (1993), An optimal design of EWMA control charts based on the median run length, *J. Stat. Comput. Simulation* 45, 169-184.
- S. Knoth (2003), EWMA schemes with non-homogeneous transition kernels, *Sequential Analysis* 22, 241-255.
- S. Knoth (2004), Fast initial response features for EWMA Control Charts, *Statistical Papers* 46, 47-64.
- K.-H. Waldmann (1986), Bounds for the distribution of the run length of geometric moving average charts, *Appl. Statist.* 35, 151-158.

See Also

xewma.sf for survival function computation of EWMA control charts in the normal case.

Examples

will follow

xtshewhart.ar1.arl *Compute ARLs of modified Shewhart control charts for AR(1) data with Student t residuals*

Description

Computation of the (zero-state) Average Run Length (ARL) for modified Shewhart charts deployed to the original AR(1) data where the residuals follow a Student t distribution.

Usage

```
xtshewhart.ar1.arl(alpha, cS, df, delta=0, N1=50, N2=30, N3=2*N2, INFI=10, mode="tan")
```

Arguments

alpha	lag 1 correlation of the data.
cS	critical value (alias to alarm limit) of the Shewhart control chart.
df	degrees of freedom – parameter of the t distribution.
delta	potential shift in the data (in-control mean is zero).
N1	number of quadrature nodes for solving the ARL integral equation, dimension of the resulting linear equation system is N1.
N2	second number of quadrature nodes for combining the probability density function of the first observation following the margin distribution and the solution of the ARL integral equation.
N3	third number of quadrature nodes for solving the left eigenfunction integral equation to determine the margin density (see Andel/Hrach, 2000), dimension of the resulting linear equation system is N3.
INFI	substitute of Inf – the left eigenfunction integral equation is defined on the whole real axis; now it is reduced to (-INFI, INFI).
mode	Controls the type of variables substitution that might improve the numerical performance. Currently, "identity", "sin", "sinh", and "tan" (default) are provided.

Details

Following the idea of Schmid (1995), $1-\alpha$ times the data turns out to be an EWMA smoothing of the underlying AR(1) residuals. Hence, by combining the solution of the EWMA ARL integral equation and the stationary distribution of the AR(1) data (here Student t distribution is assumed) one gets easily the overall ARL.

Value

It returns a single value resembling the zero-state ARL of a modified Shewhart chart.

Author(s)

Sven Knoth

References

J. Andel, K. Hrach (2000). On calculation of stationary density of autoregressive processes. *Kybernetika, Institute of Information Theory and Automation AS CR* 36(3), 311-319.

H. Kramer, W. Schmid (2000). The influence of parameter estimation on the ARL of Shewhart type charts for time series. *Statistical Papers* 41(2), 173-196.

W. Schmid (1995). On the run length of a Shewhart chart for correlated data. *Statistical Papers* 36(1), 111-130.

See Also

xtewma.ar1 for zero-state ARL computation of EWMA control charts in case of Student t distributed data.

Examples

will follow

Index

*Topic ts

dphat, 3
Ins2ewma.ar1, 4
Ins2ewma.crit, 7
mewma.ar1, 9
mewma.crit, 12
mewma.psi, 13
p.ewma.ar1, 14
phat.ewma.ar1, 16
quadrature.nodes.weights, 19
scusum.ar1, 20
scusum.crit, 22
scusums.ar1, 23
sewma.ar1, 25
sewma.ar1.prerun, 27
sewma.crit, 29
sewma.crit.prerun, 32
sewma.q, 34
sewma.q.prerun, 36
sewma.sf, 38
sewma.sf.prerun, 39
tol.lim.fac, 40
x.res.ewma.ar1, 42
xcusum.ad, 46
xcusum.ar1, 48
xcusum.crit, 51
xcusum.crit.L0h, 53
xcusum.crit.L0L1, 54
xcusum.q, 56
xcusum.sf, 57
xDcusum.ar1, 58
xDewma.ar1, 61
xDgrsr.ar1, 66
xDshewhartrunrules.ar1, 68
xewma.ad, 70
xewma.ar1, 72
xewma.ar1.prerun, 78
xewma.crit, 81
xewma.q, 82
xewma.q.prerun, 84
xewma.sf, 87
xewma.sf.prerun, 89
xgrsr.ad, 91
xgrsr.ar1, 93
xgrsr.crit, 96
xsewma.ar1, 97
xsewma.crit, 99
xsewma.q, 101
xsewma.sf, 103
xshewhart.ar1.ar1, 105
xshewhartrunrules.ar1, 106
xtcusum.ar1, 109
xtewma.ad, 110
xtewma.ar1, 112
xtewma.q, 113
xtewma.sf, 115
xtshewhart.ar1.ar1, 117

dphat, 3

Ins2ewma.ar1, 4
Ins2ewma.crit, 7

mewma.ad (mewma.ar1), 9
mewma.ar1, 9
mewma.crit, 12
mewma.psi, 13

p.ewma.ar1, 14
phat.ewma.ar1, 16
phat.ewma.crit (phat.ewma.ar1), 16
phat.ewma.lambda (phat.ewma.ar1), 16
pphat (dphat), 3

qphat (dphat), 3
quadrature.nodes.weights, 19

s.res.ewma.ar1 (x.res.ewma.ar1), 42
scusum.ar1, 20
scusum.crit, 22

scusums.ar1, 23
 sewma.ar1, 25
 sewma.ar1.prerun, 27
 sewma.crit, 29
 sewma.crit.prerun, 32
 sewma.q, 34
 sewma.q.crit.prerun (sewma.q.prerun), 36
 sewma.q.prerun, 36
 sewma.sf, 38
 sewma.sf.prerun, 39

 tol.lim.fac, 40

 x.res.ewma.ar1, 42
 xcusum.ad, 46
 xcusum.ar1, 48
 xcusum.crit, 51
 xcusum.crit.L0h, 53
 xcusum.crit.L0L1, 54
 xcusum.q, 56
 xcusum.sf, 57
 xDcusum.ar1, 58
 xDewma.ar1, 61
 xDgrsr.ar1, 66
 xDshewhartrunrules.ar1, 68
 xDshewhartrunrulesFixedm.ar1
 (xDshewhartrunrules.ar1), 68
 xewma.ad, 70
 xewma.ar1, 72
 xewma.ar1.prerun, 78
 xewma.crit, 81
 xewma.crit.prerun (xewma.ar1.prerun), 78
 xewma.q, 82
 xewma.q.crit.prerun (xewma.q.prerun), 84
 xewma.q.prerun, 84
 xewma.sf, 87
 xewma.sf.prerun, 89
 xgrsr.ad, 91
 xgrsr.ar1, 93
 xgrsr.crit, 96
 xs.res.ewma.ar1 (x.res.ewma.ar1), 42
 xs.res.ewma.pms (x.res.ewma.ar1), 42
 xsewma.ar1, 97
 xsewma.crit, 99
 xsewma.q, 101
 xsewma.sf, 103
 xshewhart.ar1.ar1, 105
 xshewhartrunrules.ad
 (xshewhartrunrules.ar1), 106

 xshewhartrunrules.ar1, 106
 xshewhartrunrules.crit
 (xshewhartrunrules.ar1), 106
 xshewhartrunrules.matrix
 (xshewhartrunrules.ar1), 106
 xtcusum.ar1, 109
 xtewma.ad, 110
 xtewma.ar1, 112
 xtewma.q, 113
 xtewma.sf, 115
 xtshewhart.ar1.ar1, 117