

free42 Repeated Measurements

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1 Metadata

The home for this HTML file is: <https://richmit.github.io/hp42/meas.html>

A PDF version of this file may be found here: <https://richmit.github.io/hp42/meas.pdf>

Files related to this document may be found on github: <https://github.com/richmit/hp42>

Directory contents:

<code>src</code>	-	The org-mode file that generated this HTML document
<code>src_42s</code>	-	Ready to convert source listings for 42s code in this document
<code>docs</code>	-	This html document and associated PDF
<code>bin</code>	-	Importable RAW program files

2 Introduction

I frequently take repeated measurements, but don't feel the need to record all the measurements in my laboratory notebook. For example, when working on my stamp collection I will measure stamp thickness at 5 locations and use the average value. Or at my electronics bench I may measure inductance 3 or 5 times, and use the midrange as the value. The application described below is designed to make that process more automated and less error prone.

3 Supported Methods

The two most common methods for estimating & reporting measurement uncertainty are nicely documented in NIST Technical Note 1297. The first method assumes the non-systematic components of measurement errors are statistically independent and normally distributed. In this case the measurement is taken to be the mean (μ), and the standard uncertainty (u) is defined as the sample standard deviation (s). The second method assumes a uniform error distribution – which I will refer to as rectangular in this document in order to avoid confusion with u . In this case the measurement is assumed to be the midrange ($MR = (x_{\cdot ax} + x_{\cdot \ddot{a}x})/2$), and the standard uncertainty is defined as $u = (x_{\cdot ax} - x_{\cdot \ddot{a}x})/(2\sqrt{3})$. The MEAS application supports both of these methods in addition to one based on rank statistics where the measurement is taken to be the median and the uncertainty is one half the interquartile range. While this last scheme is not easily related to a standard probability distribution, it has found some popularity – particularly in the life sciences.

Frequently the standard uncertainty is expanded by a factor (k) in order to provide a probabilistic uncertainty interval or confidence interval. The MEAS application supports only a fixed set of values for k for automatic reporting.

Finally, the application provides a number of raw statistics that might be useful for error analysis:

- Mean or arithmetic average (μ)
- Midrange (MR)
- Range
- Standard deviation (σ)
- Population standard deviation (s)
- Number of observations (N)
- Sum
- Sum of squares
- First quartile (Q_1)
- Second quartile or median (Md or Q_2)
- Third quartile (Q_3)
- Interquartile range (IQR)

4 Setup

The last menu provides configuration options.

4.1 Reporting Scheme

The reporting scheme is set via the first menu button – the current selection is displayed in the menu label (N=Normal, R=Rectangular, and Q=Quartiles). This key cycles between the schemes when pressed. Note that it also defaults the coverage factor (the second menu button)!

4.2 Coverage Factors

The coverage factor used to compute the expanded uncertainty is set via the second menu key. Repeatedly pressing this button will cycle through predefined values appropriate for the already selected reporting scheme.

This option is used both for reports and the expanded uncertainty computations elsewhere in the menus ([kuN], [kuR], & [kuQ]). It is not possible to set the coverage factor to an arbitrary value; however, the sample standard deviation ([SSD]), rectangular variance ([RtVA]), and interquartile range ([IQR]) are all in the menus if you need more flexibility.

For normally distributed errors the following coverage factors are supported.

Confidence %	Coverage Factor
68.27	1
95.45	2
99.73	3

Note: This same set of coverage factors are also available when using the Quartile scheme; however, they are somewhat difficult to interpret from a probabilistic standpoint.

For errors with a rectangular distribution the following coverage factors are supported.

Coverage Factor
1
$\sqrt{3}$

4.3 Automatic Reporting

A report can be generated upon entering a specified number of measurements. This is very handy when a batch of items needs to be measured, and one wishes to do a fixed number of measurements per item. To set the automatic report count provide an integer in X, and use this menu key. The current value is displayed as part of the menu label. A dash (-) means no automatic reporting is configured. Use zero to turn off reporting.

5 Reporting

I find that most of the time I use units such that measurements have integer values. For example with paper thickness measurements I will use micrometers in a range between 700 and 1100. For other philatelic applications I may use millimeters with one or, rarely, two decimals. For these applications it is possible to fit the measurement value, uncertainty, max, and min all on the screen at once assuming FIX, SCI, or ENG has been set correctly. The report function attempts to use this compact reporting method if possible. Otherwise it uses the first line for the measurement estimate and the second line for the expanded uncertainty.

The measurement and expanded uncertainty are reported according to the selected reporting scheme and coverage factor. See the setup menu. Reports can be automatically generated upon entry of a configurable number of measurements. See the setup menu.

MNU	LL	Key	Description	Notes
LBL 70	LBL 98	M+	Add a new measurement	
M-	LBL 97	M-	Delete last measurement	
EDIT	LBL 38	EDIT	Edit MeDAT	Requires N>0 – i.e. can't edit an empty MeDAT matrix!
REP	LBL 96	REP	Display Report	The report format & content is controlled by the settings.
→STK	LBL 39	→STK	Report to Stack	Y: Measurement Estimate X: Expanded Uncertainty
CLRM	LBL 95	CLRM	Clear all measurements	
μ	LBL 94	μ	Arithmetic Mean	Normal Errors: Measurement estimate
kuN	LBL 93	kuN	ERR: k*SSD	Normal Errors: Expanded uncertainty estimate
MR	LBL 92	MR	Midrange	Rectangular Errors: Measurement estimate
kuR	LBL 91	kuR	ERR: k*(MAX-MIN)/(2*sqrt(3))	Rectangular Errors: Expanded uncertainty estimate
MIN	LBL 89	MIN	Minimum value	
MAX	LBL 88	MAX	Maximum value	
PSD	LBL 87	PSD	Population Standard Deviation	The one with n on the bottom. ;) Requires N>0
SSD	LBL 86	SSD	Sample Standard Deviation	The one with n-1 on the bottom. ;) Requires N>1
RNG	LBL 85	RNG	Range: MAX-MIN	
RtVA	LBL 90	RtVA	Rectangular Variance	(MAX-MIN)/(2*sqrt(3))
N	LBL 84	N	Number of measurements	Number of rows in MeDAT
SUMS	LBL 83	SUMS	Y: Sum Squared X: Sum	
Q25	LBL 35	Q25	First Quartile (25%)	Requires N>2
MED	LBL 77	MED	Median	Quartile Scheme: Measurement estimate. Requires N>2
Q75	LBL 36	Q75	Third Quartile (75%)	Requires N>2
IQR	LBL 34	IQR	Interquartile range (Q75-Q25)	Requires N>2
kuQ	LBL 46	kuQ	ERR: k*(Q75-Q25)/2	Quartile Scheme: Expanded uncertainty estimate. Requires N>2
□□□□		□□□□		
LBL 79	LBL 82	S:?	Reporting Scheme	Cycle between N=Normal, R=Rectangular, & Q=Quartiles
LBL 48	LBL 81	K:?	Coverage Factor	Cycle through predefined values for current reporting scheme
LBL 78	LBL 80	A:?	Auto Report Count	Automatically generate a report on N'th measurement entry
REP	LBL 96	REP	Display Report	Duplicated here so you can see reports after option changes
→STK	LBL 39	→STK	Report to Stack	Duplicated here so you can see reports after option changes
RESET	RSTMES	RESET	Delete data & set defaults	Use the global label RSTMES to access outside application

6 Application Menu

Notes:

- Please ignore the first two columns in the table – they are used to auto-generate the menu code for the application.
- I use PSD & SSD to be explicit and avoid confusion with the 42s internal function SDEV (which is PSD)
- Method used for the first & third quartile:
 - Q1 is the median of the lower half of the data while Q3 is the median of the upper half
 - If N is odd, we do not include the median (the central value in the ordered list) in either half.
 - If N is even, we split this data set exactly in half.
- RSTMES is a global label that will set all global variables used by MEAS to default values

7 Global Variables

Application state is maintained in a number of global variables.

Variable	Description	
MeDAT	Measurement Matrix	Feel free to edit this directly
MeRSC	Reporting Scheme	Use the setup menu to change this one
MeCFA	Coverage Factor	Use the setup menu to change this one
MeTGN	Auto Report Count	Use the setup menu to change this one

8 Use

In use the application is quite like the built in statistics application in that [M+] & [M+] add and delete measurements. All measurements are stored in a matrix named MeDAT. Feel free to edit this matrix with the MATRIX menu.

The [REP] key will generate a report. Reports can also be generated automatically when a set number of measurements have been entered (see the setup menu).

Menu page two, three, & four compute various statistics useful for uncertainty reporting. Page two has the most common statistics, page three is useful for custom uncertainty computations, and page four has rank based statistics.

Menu page five is for setup. The reporting scheme impacts reporting (menu page one: [REP]). The coverage factor impacts reporting (menu page one: [REP]) and the expanded uncertainty computations (menu page two & four: [kuN], [kuR], & [kuQ]). The automatic reporting option impacts the add measurement function (menu page one: [M+]) such that a report is automatically generated when a specified number of measurements have been entered.

9 Future

Some things I might do some day...

- A graphical representation showing the points and various confidence intervals would be cool
- It would be neat to see a live dot plot of the measurements as they are being entered
- Arbitrary k values
- Support the larger screen when running on the DM42
- Drop the data into the built in statistics tool
- Add option to use "Tukey's hinges" for the first & third quartiles
- ~~Make the sub-functions perfect (i.e. minimally alter stack/last X)~~
- ~~Add rank statistics~~
- ~~Add the median & interquartile range reporting scheme used in biology~~
- ~~Make the setup menu not alter the stack~~
- Add a printed report listing data and both normal & square estimates for all coverage factors

10 Code

10.1 Menu Code

```
(MJR-generate-42-menu-code "MEAS" 0 tbl 0 1 'stay 'up 'auto #'MJR-custom-gen-lab #'MJR-custom-gen-sub)
```

```
@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@ (MEAS)
```

```
@@@ DSC: Auto-generated menu program
```

```
LBL "MEAS"
```

```
LBL 01          @@@@ Page 1 of menu MEAS
```

```
CLMENU
```

```
XEQ 70
```

```
KEY 1 XEQ 98
```

```
"M-
```

```
KEY 2 XEQ 97
```

```
"EDIT"
```

```
KEY 3 XEQ 38
```

```
"REP"
```

```
KEY 4 XEQ 96
```

```
"→STK"
```

```
KEY 5 XEQ 39
```

```
"CLRM"
```

```
KEY 6 XEQ 95
```

```
KEY 7 GTO 05
```

```
KEY 8 GTO 02
```

```
KEY 9 GTO 00
```

```
MENU
```

```
STOP
```

```
GTO 01
```

```
LBL 02          @@@@ Page 2 of menu MEAS
```

```
CLMENU
```

```
"μ"
```

```
KEY 1 XEQ 94
```

```
"kuN"
```

```
KEY 2 XEQ 93
```

```
"MR"
```

```
KEY 3 XEQ 92
```

```
"kuR"
```

```
KEY 4 XEQ 91
```

```
"MIN"
```

```
KEY 5 XEQ 89
```

```
"MAX"
```

```
KEY 6 XEQ 88
```

```
KEY 7 GTO 01
```

```
KEY 8 GTO 03
```

```
KEY 9 GTO 00
```

```
MENU
```

```
STOP
```

```
GTO 02
```

```
LBL 03          @@@@ Page 3 of menu MEAS
```

```
CLMENU
```

```
"PSD"
```


AVIEW
RTN

```
@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@
@@@ DSC: EDIT: LABEL 38
LBL 38 @NM@ EDIT
FUNC 00
SF 25
RCL "MeDAT"
FC?C 25
GTO 99
R↓
EDITN "MeDAT"
"Enter data; R/S"
└" to end"
PROMPT
EXITALL
XEQ 47 @NM@ SMLREP
RTN
```

```
@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@
@@@ DSC: M+: LABEL 70
LBL 70 @NM@ M+_LBL
FUNC 00
XEQ 49 @NM@ DEFVAR
"M+"
RTN
```

```
@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@
@@@ DSC: Set unset variables to defaults
LBL 49 @NM@ DEFVAR
FUNC 00
0
SF 25
RCL "MeRSC"
FC?C 25
STO "MeRSC"
SF 25
RCL "MeCFA"
FC?C 25
STO "MeCFA"
SF 25
RCL "MeTGN"
FC?C 25
STO "MeTGN"
SF 25
RCL "MeRDM"
FC?C 25
STO "MeRDM"
SF 25
RCL "MeREP"
FC?C 25
STO "MeREP"
R↓
RTN
```

```
@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@
@@@ DSC: A: LABEL 78
LBL 78 @NM@ A_LBL
FUNC 00
"A:"
RCL "MeTGN"
X=0?
└"_"
X≠0?
AIP
R↓
RTN
```

```
@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@
@@@ DSC: S: LABEL 79
LBL 79 @NM@ S_LAB
FUNC 00
"S:"
RCL "MeRSC"
50
```

+
XEQ IND ST X
R↓
RTN

@@
@@@ DSC: k: LABEL 48
LBL 48 @NM@ k_LAB
FUNC 00
"k:"
XEQ 22 @@@@ |-CNA
R↓
RTN

@@
@@@ DSC: A: ACTION 80
@@@ A can be 0 or in [3,99]
LBL 80 @NM@ A_ACT
FUNC 00
0
X≤Y?
R↓
99
X≥Y?
R↓
STO "MeTGN"
X=0?
RTN
"WARN: Too"
|" small:"
3
X>Y?
|" Q"
R↓
2
X>Y?
|" & N"
R↓
3
X>Y?
AVIEW
R↓
R↓
RTN

@@
@@@ DSC: k: ACTION 81
LBL 81 @NM@ k_ACT
FUNC 00
1
RCL+ "MeCFA"
RCL "MeRSC"
1
X=Y?
GTO 58
R↓
R↓
4
GTO 57
LBL 58
R↓
R↓
2
LBL 57
MOD
STO "MeCFA"
R↓
RTN

@@
@@@ DSC: S: ACTION 82
LBL 82 @NM@ S_ACT
FUNC 00
1
RCL+ "MeRSC"
3

MOD
STO "MeRSC"
R↓
0
STO "MeCFA"
R↓
RTN

@@
@@@ DSC: PSD 87
LBL 87 @NM@ PSD
FUNC 01
SF 25
INDEX "MeDAT"
FC?C 25
GTO 99
XEQ 83 @NM@ SUMS
XEQ 84 @NM@ N
X<>Y
X↑2
RCL÷ ST Y
RCL÷ ST Y
RCL ST Z
RCL ST Z
÷
X<>Y
-
SQRT
RTN

@@
@@@ DSC: M- 97
LBL 97 @NM@ M-
FUNC 00
SF 25
RCL "MeDAT"
FC?C 25
GTO 72 @@@ MeDAT is missing
DIM?
R↓
1
X=Y?
GTO 72 @@@ MeDAT has only one row
SF 25 @@@ Index MeDAT
INDEX "MeDAT"
FC?C 25
GTO 72 @@@ MeDAT is missing
J-
RCLEL
DELR
XEQ 47 @NM@ SMLREP
RTN
LBL 72
XEQ 95 @NM@ CLRM
RTN

@@
@@@ DSC: CLRM 95
LBL 95 @NM@ CLRM
FUNC 00
SF 25
INDEX "MeDAT"
CLV "MeDAT"
CF 25
"MeDAT Cleared"
AVIEW
RTN

@@
@@@ DSC: M+ 98
LBL 98 @NM@ M+
FUNC 00
REAL?
GTO 56
"ERR: Bad Value"
AVIEW


```

@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@
@@@ DSC: SSD 86
LBL 86 @NM@ SSD
FUNC 01
SF 25
RCL "MeDAT"
FC?C 25
GTO 99
DIM?
R↓
2
X>Y?
GTO 75
XEQ 83 @NM@ SUMS
XEQ 84 @NM@ N
X<>Y
X↑2
RCL÷ ST Y
RCL ST Z
X<>Y
-
X<>Y
1
-
÷
SQRT
X<>Y
R↓
RTN

```

```

@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@
@@@ DSC:  $\mu$  (mean) 94
LBL 94 @NM@  $\mu$ 
FUNC 01
SF 25
INDEX "MeDAT"
FC?C 25
GTO 99
XEQ 83 @NM@ SUMS
X<>Y
R↓
XEQ 84 @NM@ N
÷
RTN

```

```

@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@
@@@ DSC: SUMS 83
LBL 83 @NM@ SUMS
FUNC 02
SF 25
INDEX "MeDAT"
FC?C 25
GTO 99
0
0
LBL 33
RCLEL
STO+ ST Y
X↑2
STO+ ST Z
R↓
J+
FC? 77
GTO 33
RTN

```

```

@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@
@@@ DSC: N 84
LBL 84 @NM@ N
FUNC 01
SF 25
RCL "MeDAT"
FS?C 25
GTO 54
0
RTN

```

LBL 54
DIM?
R↓
RTN

@@
@@@ DSC: MED (median) 77
@@@ FAQ: Needs at least 3 values
LBL 77 @NM@ MED
FUNC 01
XEQ 74
R↓
RTN

@@
@@@ DSC: Q1 (First quartile) 35
@@@ FAQ: Needs at least 3 values
LBL 35 @NM@ Q1
FUNC 01
XEQ 74
R↓
R↓
RTN

@@
@@@ DSC: Q3 (Third quartile) 36
@@@ FAQ: Needs at least 3 values
LBL 36 @NM@ Q3
FUNC 01
XEQ 74
RTN

@@
@@@ DSC: IQR (Interquartile Range) 34
@@@ FAQ: Needs at least 3 values
LBL 34 @NM@ IQR
FUNC 01
XEQ 74
X<>Y
R↓
X<>Y
-
RTN

@@
@@@ DSC: kuQ (Quartiles uncertainty) 46
@@@ FAQ: Needs at least 3 values
LBL 46 @NM@ kuQ
FUNC 01
XEQ 74
X<>Y
R↓
X<>Y
-
2
/
RCL "MeCFA"
60
+
XEQ IND ST X
X<>Y
R↓
x
RTN

@@
@@@ DSC: QUART (quartiles) 74
@@@ OUT: X: Q3 Y: Q2 Z: Q1
@@@ FAQ: Needs at least 3 values
LBL 74 @NM@ QUART
FUNC 03
L4STK
SF 25
RCL "MeDAT"
FC?C 25
GTO 99


```

STOIJ
R↓
RCLEL
X<>Y
1
+
1
STOIJ
R↓
R↓
RCLEL
+
2
/
RTN
LBL 73
@@@ On
R↓
1
STOIJ
R↓
R↓
RCLEL
RTN

@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@
@@@ DSC: "ERR: No MeDAT!" 99
LBL 99
@@@ Not FUNC -- NOT A XEQ TARGET, but A GTO TARGET
"ERR: No MeDAT!"
AVIEW
RTN

@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@
@@@ DSC: "ERR: MeDAT Too Small!" 75
LBL 75
@@@ Not FUNC -- NOT A XEQ TARGET, but A GTO TARGET
"ERR: MeDAT "
|-"Too Small!"
AVIEW
RTN

@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@
@@@ DSC: Coverage values
LBL 60          @@@ Value for coverage factor 0
FUNC 01
1
RTN
LBL 61          @@@ Value for coverage factor 1
FUNC 01
RCL "MeRSC"
1
X≠Y?
GTO 59
R↓
3
SQRT
RTN
LBL 59
R↓
R↓
2
RTN
LBL 62          @@@ Value for coverage factor 2
FUNC 01
3
RTN
LBL 63          @@@ Value for coverage factor 3
FUNC 01
4
RTN
LBL 64          @@@ Value for coverage factor 4
FUNC 01
999
RTN

```



```

@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@
@@@@ DSC: Coverage Names
LBL 65          @@@@ Name for coverage factor 0
├"1"
RTN
LBL 66          @@@@ Name for coverage factor 1
RCL "MeRSC"
1
X=Y?
├"√3"
X≠Y?
├"2"
R↓
R↓
RTN
LBL 67          @@@@ Name for coverage factor 2
├"3"
RTN
LBL 68          @@@@ Name for coverage factor 3
├"4"
RTN
LBL 69          @@@@ Name for coverage factor 4
├"999"
RTN

@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@
@@@@ DSC: reporting scheme Names
LBL 50          @@@@ Name for reporting scheme 0
├"N"
RTN
LBL 51          @@@@ Name for reporting scheme 1
├"R"
RTN
LBL 52          @@@@ Name for reporting scheme 2
├"Q"
RTN

@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@
END

```

11 EOF