

Butterworth Filter for Microsoft Excel (version 2): manual

A “fourth order zero-phase shift” butterworth low-pass data noise filter with user-defined cut-off frequency, with the possibility to differentiate the filtered data into velocities (first derivate against time) and accelerations (second derivate against time). Version 2 can also be used adaptively to fine-tune cut-off frequencies according to local signal characteristics by specifying a range of cut-off frequencies and the number of iterations to be performed (see Erer 2007, J. Biomech.).

Written in ‘Microsoft Visual Basic For Applications’ for Microsoft Excel 2000 by Sam Van Wassenbergh (University of Antwerp), 6 june 2007. Formulae in the program are based on the book “Biomechanics and Motor Control of Human Movement” by D.A. Winter (2004, third edition) and the article “Adaptive usage of the Butterworth digital filter” by K. Erer (2007, Journal of Biomechanics, <http://dx.doi.org/10.1016/j.jbiomech.2007.02.019>)

How to add this function to Excel?

- 1) The file named “Butterworth Filter.xla” is on your hard drive
 - 2) Open Excel
 - 3) In the menu bar, go to Tools -> Add-Inns -> Browse (locate and select the above .xla file) -> ok
- Unless the “Butterworth Filter.xla” file changes position, its code will become automatically available upon start-up of MS Excel.

How does it work?


The following things are necessary to make the program work:

A) unmodified Butterworth filter (single, constant cut-off frequency)

- 1) one column has a cell with the word “time” (exactly this word, no capital letters!) as content, and with time values (in seconds!) in the rows underneath the “time”-cell (minimal 2 cells), the data must have a constant sampling rate.
- 2) each column with data needed to be filtered has a column on its right hand side with title cell “butfilt1” (exactly this word) for the first data-column, “butfilt2” (exactly this word) for the second data-column, “butfilt3” (exactly this word) for the third data-column... for maximum 50 data-columns.
- 3) above each “butfilt#”-cell, a number is given for the cutoff-frequency to be used in the filtering procedure.

The following table gives an example of how this looks like in an Excel-worksheet: the words colored in red must be exact, and the numbers in green (above each “butfilt#”-column; cutoff-frequencies) must be given at these locations in the worksheet. The italic numbers are the output of the program.

**By typing “le” into the cell indicated by the arrow (1 row above the data title), the default boundary condition (i.e. no movement assumed prior to time 0 and after the final data point) is changed to a procedure where two time steps are extrapolated before and after the entered data using a linear regression on the first and last three points of the data. In this way, a constant velocity (but zero acceleration) is assumed at the boundaries of the data. “le” refers to linear extrapolation.



		25		
time	data	butfilt1	velocity	acceleration
0	12,2	12,2717	6,113499	848,208
0,004	12,4	12,32061	12,89916	1047,643
0,008	12,5	12,3749	14,49465	572,3173
0,012	12,4	12,43657	17,4777	923,6059
0,016	12,3	12,51472	21,88349	899,9212
	12,5	12,61164	24,67707	83,41299
	12,9	12,71214	22,5508	-1171,42
	12,8	12,79204	15,30574	-1986,66
	13	12,83458	6,657555	-1745,68
	13,5	12,8453	1,340317	-664,655


- 4) if you want the filtered data to be differentiated, make a column on the right side of any butfilt# column with title “velocity” (for first derivate) or “acceleration” (for second derivate). Note that there is no number indexing in title cells “velocity” and “acceleration”, they just have to be on the right side adjacent to the “butfilt#” column. First-order central differences are used in all derivative calculations.
- 5) Run the program by the short-cut keys: **CTRL SHIFT B**

B) Adaptive Butterworth filter (variable cut-off frequency, solved iteratively)

- 1) one column has a cell with the word “time” (exactly this word, no capital letters!) as content, and with time values (in seconds!) in the rows underneath the “time”-cell (minimal 2 cells), the data must have a constant sampling rate.
- 2) each column with data needed to be filtered has a column on its right hand side with title cell “butfilt-ad1” (exactly this word) for the first data-column, “butfilt-ad2” (exactly this word) for the second data-column, “butfilt-ad3” (exactly this word) for the third data-column... for maximum 50 data-columns.
- 3) above each “butfilt-ad#”-cell, three cells provide the settings for the adaptive filter. The first and second cell above “butfilt-ad#” give the range of cut-off frequencies to be used (minimum and maximum; random order). The third cell above “butfilt-ad#” determines the number of iterations. Six iterations already yielded a good result according to Erer (2007).
- 4) if you want the filtered data to be differentiated, make a column on the right side of any butfilt# column with title “velocity” (for first derivate) or “acceleration” (for second derivate). Note that there is no number indexing in title cells “velocity” and “acceleration”, they just have to be on the right side adjacent to the “butfilt#” column. First-order central differences are used in all derivative calculations.
- 5) Run the program by the short-cut keys: **CTRL SHIFT B**

The following table gives an example of how this looks like in an Excel-worksheet: the words colored in red must be exact, and the numbers in green (above each “butfilt-ad#”-column; cutoff-frequency range, number of iteration) must be given at these locations in the worksheet. The italic numbers are the output of the program.

**By typing “le” into the cell indicated by the arrow (1 row above the data title), the default boundary condition (i.e. no movement assumed prior to time 0 and after the final data point) is changed to a procedure where two time steps are extrapolated before and after the entered data using a linear regression on the first and last three points of the data. In this way, a constant velocity (but zero acceleration) is assumed at the boundaries of the data. “le” refers to linear extrapolation.



		6		
		80		
	le	15		
time	data	butfilt-ad1	velocity	cutoff
0	12,2	12,30049	10,97065	35,50759
0,004	12,4	12,34368	11,05805	38,66301
0,008	12,5	12,38896	12,95491	45,9764
0,012	12,4	12,44732	18,22743	59,08205
0,016	12,3	12,53478	24,77432	73,72621
	12,5	12,64551	28,02184	76,70625
	12,9	12,75895	29,46276	74,48843
	12,8	12,88121	28,88167	70,06542
	13	12,99001	18,41771	61,56122
	13,5	13,02856	15,4909	58,59081

(info: pre-filtering is done with the user-defined maximal cut-off frequency, postfiltering is done using the highest cut-off frequency from the last iteration increased by 20%. As mentioned, first-order central difference approximations are used in all derivative calculations.)