



GMWM Package - Part II

Automatic and Computationally Efficient Method For Model Selection In Inertial Sensor Calibration

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The GMWM package in action

Outline

1 Visualizing the signal(s):

- Is the signal disturbed (contaminated)?
- Which models could best describe the visualized WV?

2 Estimating the model(s)

- The `gmwm.imu()` function for parameter estimation
- The options for estimation

3 Inference

- Confidence intervals for the parameters
- Goodness-of-fit of the model to the signal

4 Model Selection

- The efficient computation of the WVIC
- Model selection from a set of user-specified models
- Automatic model selection from a set of all sub-models of a single user-specified model

The GMWM package in action

Getting to know the package

The package comes with an example dataset called `imu6`

- The data comes from the calibration of an XSens MTi-G sensor
- To use the data within the R session:
 - 1 Load the `gmwmdata` package (separate from the `gmwm` package)
 - 2 Make the dataset available in the session by typing `data(imu6)`
- Load external data (e.g. binary data) with `read.imu()`

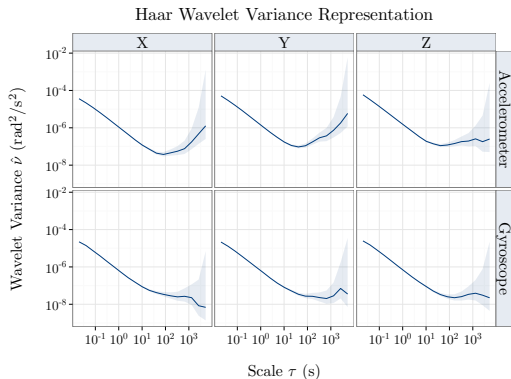
```
install.packages("gmwmdata")
library(gmwmdata)
data(imu6)
head(imu6)
```

	Gyro. X	Gyro. Y	Gyro. Z	Accel. X	Accel. Y	Accel. Z
1	-0.011138	-0.017646	-0.009531	1.083731	0.023897	9.638113
2	-0.006765	-0.013657	-0.021974	1.059858	0.042061	9.646901
3

Visualizing the data

The function `wvar.imu()`

Once the calibration data has been entered, it is possible to plot the observed WV vs τ on a log-log scale



R code:

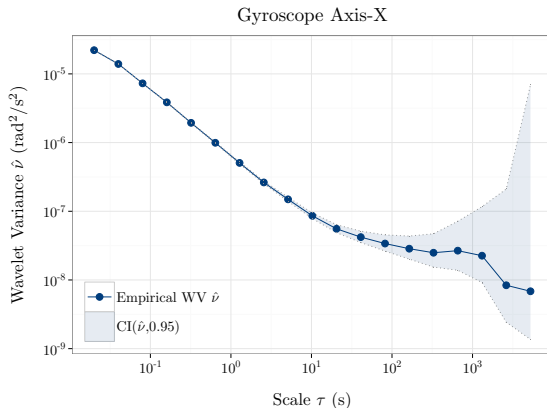
```
imu.obj = imu(imu6,  
gyroscope = 1:3,  
accelerometer = 4:6)  
wv = wvar.imu(imu.obj)  
plot(wv)
```

(Run time: 3.70 [sec])

Visualizing the data

The function `wvar()`

It is obviously possible to plot the WV from the axis of an accelerometer or gyroscope individually



R code:

```
WV.gx = wvar(imu6[,1])  
plot(WV.gx)
```

(Run time: 0.65 [sec])

The Allan variance can also be computed through the function `avar()`

The `gmwm.imu()` function

The function tailor-made for IMU error modeling is `gmwm.imu()`

Main arguments of the `gmwm.imu()` function

- `model`: The structure of the model is specified through this argument
- `data`: The signal to be modelled
- `compute.v`: The method for computing the weighting matrix Ω
 - `fast`: Estimated diagonal matrix
 - `diag`: Use a diagonal matrix with the asymptotic variance of $\hat{\nu}$
 - `bootstrap`: Estimate Ω through parametric bootstrap

The model argument

The GMWM package can estimate each specific model or any latent model made by a combination of all or a subset of the following models

- `AR1()`: a first-order autoregressive process (reparametrization of Gauss-Markov process)
- `WN()`: white noise process
- `QN()`: quantization noise (rounding error)
- `RW()`: random walk process
- `DR()`: drift
- `AR()`: p -order autoregressive process
- `MA()`: q -order moving average process
- `ARMA()`: autoregressive-moving average processes

Latent model syntax

To specify a latent model we use the sign “+” between the available models while the `AR1()` model can be included more than once (say k times) and is can be specified as `k*AR1()`, for example

- `ARMA()+WN()+RW()`
- `3*AR1()+DR()`

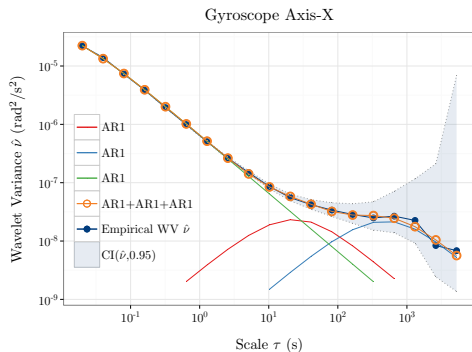
Convergence

If the `gmwm.imu()` function has problems of convergence, one can specify **starting values** for the parameters using the brackets in the syntax of each model (e.g. `WN(sigma2=0.5)`)

GMWM estimation

Visually assessing the fit

The function `plot()` applied to the object of a GMWM estimation allows to see how well the WV implied by the estimated model fits the observed WV



R code:

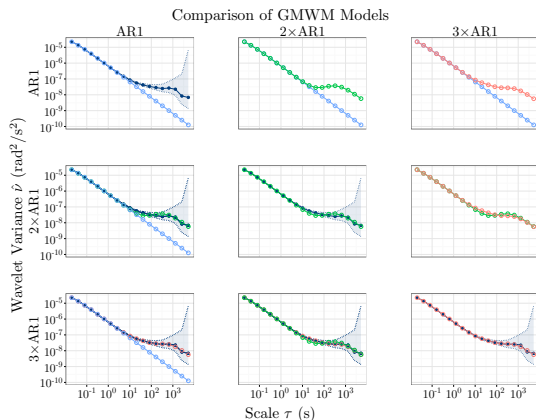
```
mod = gmwm.imu(3*AR1(),  
imu6[,1]) plot(mod,  
process.decomp = T)
```

(Run time: 0.56 [sec])

Model Comparison

Suppose we want to compare three models...

AR1(), 2*AR1() and 3*AR1()



R code:

```
Xt = imu[,1]  
m1 = gmwm.imu(AR1(),Xt)  
m2 = gmwm.imu(2*AR1(),Xt)  
m3 = gmwm.imu(3*AR1(),Xt)  
compare.models(m1, m2, m3)
```

(Run time: 5.20 [sec])

Inference

Output of estimation

Aside from the value of the estimated parameters, the output of the function `gmwm.imu` provides other information for inference which include **confidence intervals** and **goodness of fit** test (GoF)

```
mod = gmwm.imu(2*AR1(), imu6[,1])  
summary(mod, inference = T)
```

Model Information:

	Estimates	CI Low	CI High	SE
AR1	9.998700e-01	9.998336e-01	9.999064e-01	2.211547e-05
SIGMA2	5.223319e-11	4.343878e-11	6.102759e-11	5.346620e-12
AR1	1.265324e-01	1.265324e-01	1.265324e-01	1.765050e-08
SIGMA2	5.031185e-05	5.021566e-05	5.040805e-05	5.848209e-08

* The initial values of the parameters used in the minimization of the GMM objective function were generated by the program underneath seed: 1337.

Objective Function: 20.9297

Asymptotic Goodness of Fit:

Test Statistic: 903.8 on 15 degrees of freedom

The resulting p-value is: 0

WIC model selection

Two options for model selection

- **Manual:** the function `rank.models()` allows the user to specify the set of models from which to select
- **Automatic:** the function `auto.imu()` allows to specify one single model from which all sub-models are generated to create a set from which to select

R code:

```
rank.models(3*AR1()+WN(),  
2*AR1()+QN(), imu6[,1], nested =  
F, bootstrap = F, model.type="imu",  
robust = F)
```

```
mod.res = auto.imu(imu6, model  
= 3*AR1()+WN()+RW()+QN()+DR(),  
bootstrap = F, robust = F)
```

WIC model selection

Automatic IMU model selection

Suppose we want to apply the `auto.imu()` function to the X-axis gyroscope in the `imu` dataset and consider all model combinations within the $4*AR1() + WN() + RW()$ model

```
Xt = imu6[,1]
mod = 4*AR1()+WN()+RW()
mod.sel = auto.imu(Xt, model = mod)
summary(mod.sel)
```

The model ranking for data column 1:

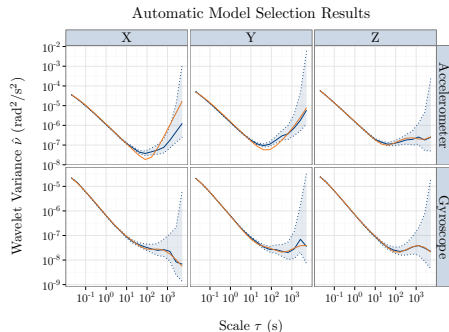
				Obj Fun	Optimism	Criterion	GoF	P-Value
1.	AR1	AR1	AR1	17.2769	0.2974	17.5743		0
2.	AR1	AR1	AR1 RW	17.2679	0.3139	17.5818		0
3.	AR1	AR1	AR1 AR1	17.6022	0.4330	18.0351		0
4.	AR1	AR1	RW	20.1044	0.4871	20.5915		0
5.	AR1	AR1		20.9864	0.2070	21.1933		0
...								
19.	RW			28420.4972	0.0160	28420.5132		0

(Run time: 50.25 [sec] \approx 14x faster than the bootstrap option 685.4 [sec])

WIC Model Selection

Visualizing the Automatic IMU Model Selection

We can observe the results of the `auto.imu()` function by requesting a plot. The plot will contain the empirical wavelet variance in addition to the best implied wavelet variance that we find. In this particular case, we used the defaults of the `auto.imu()` (63 models \times 6 columns).



R code:

```
imu.obj = imu(imu6, gyroscope = 1:3,  
accelerometer = 4:6, axis = c('X',  
'Y', 'Z'))  
auto.mod = auto.imu(imu.obj)  
plot(auto.mod)  
(Run time: 377.77 [sec])
```

Upcoming features

Aside from **fine-tuning existing features** of the package (additional options, function optimization, support documentation, etc.), the GMWM package will be updated with the following features

- Sensor calibration under **dynamic conditions**

$$Y_t = \rho_t Y_{t-1} + \epsilon_t$$

- **Multivariate latent models**

$$Y_t^{(x)} = V_t + W_t^{(x)}$$

$$Y_t^{(y)} = V_t + W_t^{(y)}$$

$$Y_t^{(z)} = V_t + W_t^{(z)}$$

- Others (e.g. additional moments for the GMWM (AGMWM), other wavelet filters, unit-root and independence testing)

Thank you very much for your attention!

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Any questions?

More info...

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