Univerzitet u Beogradu, Građevinski fakultet

Kalibracija senzora i filtriranje signala

Merenja u hidrotehnici

3. Vežba

doc. dr Damjan Ivetić

dr Miloš Milašinović

prof. dr Dušan Prodanović

MERENJE OSNOVNIH VELIČINA U HIDROTEHNICI

- **Merenje pritiska:** pijezorezistivni, kapacitivni, induktivni senzori
- **Merenje nivoa vode:** ultrazvučni senzori, senzori pritiska + preračunavanje
- **Merenje brzine:** UZV, EM, hot-wire i hot-film, ...
- **Merenje protoka:** volumetrijsko, UZV, EM, ...

- **+ merenje kvaliteta vode:** pH, mutnoća, elektroprovodnost

Da bi uređaj mogli da koristimo za merenje, on mora biti KALIBRISAN!

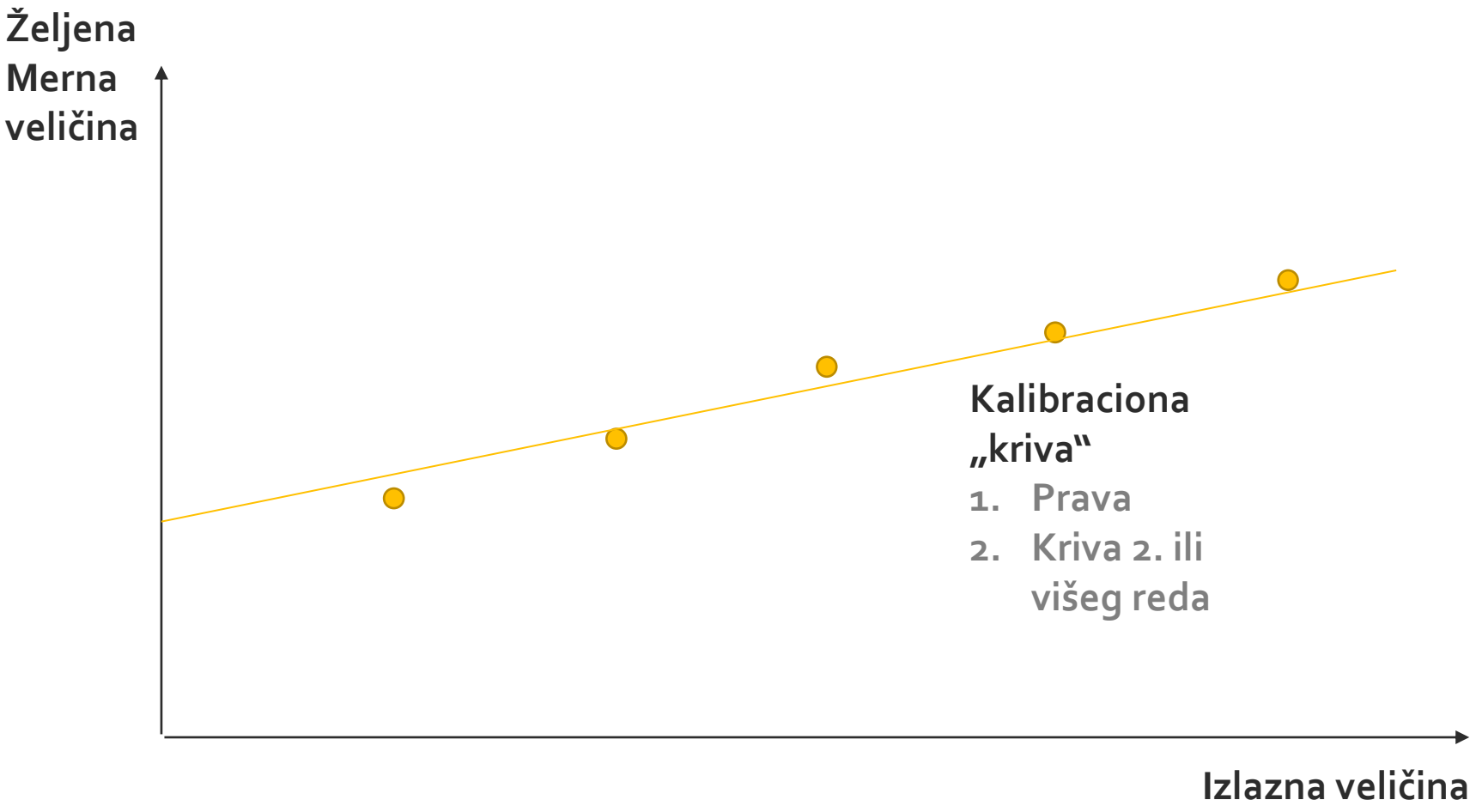
DEFINICIJA KALIBRACIJE

- International Bureau of Weights and Measures **(BIPM)–**

"Operation that, under specified conditions, in a first step, establishes a relation between the quantity values with measurement uncertainties provided by measurement standards and corresponding indications with associated measurement uncertainties (of the calibrated instrument or secondary standard) and, in a second step, uses this information to establish a relation for obtaining a measurement result from an indication."

Uspostavljanje funkcionalne zavisnosti između izlazne veličine i željene merne veličine.

PRIMERI


Željena
Merna
veličina
Kalibraciona
„kriva“
1. Prava
2. Kriva 2. ili
višeg reda
Izlazna veličina

PRIMERI

1. Kalibracija EM senzora brzine (primer)

$$V_{et}\left[\frac{m}{s}\right] = f\left(U[mV]\right) \qquad V_{et} = A \cdot U + B$$

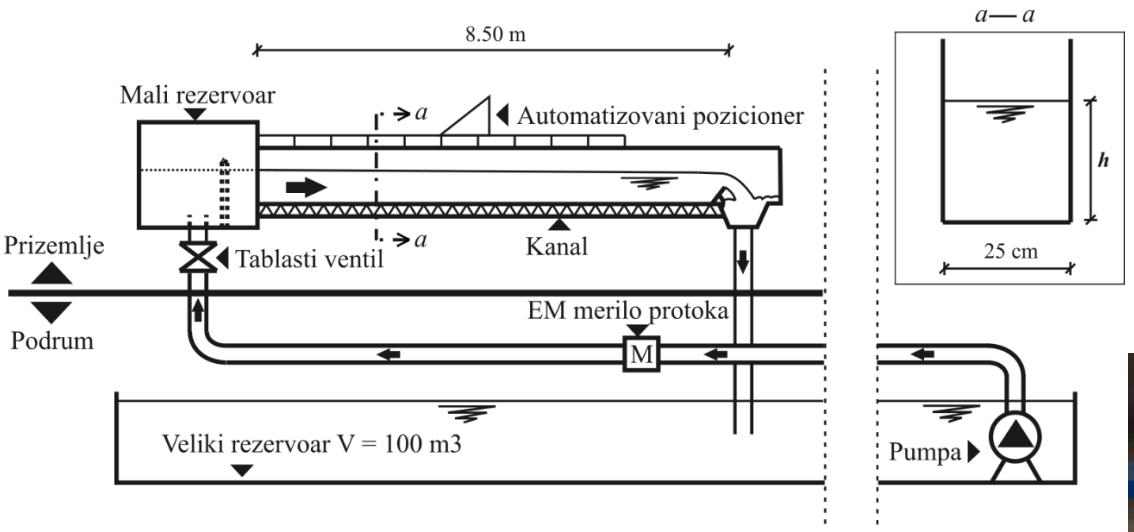
Pitamo se prvo šta želimo od senzora?

Protok? $\mathrm{Q} = \mathrm{A} \cdot V_{sr}$

Znači da je: $V_{et} = V_{sr}$

PRIMERI

1. Kalibracija EM senzora brzine



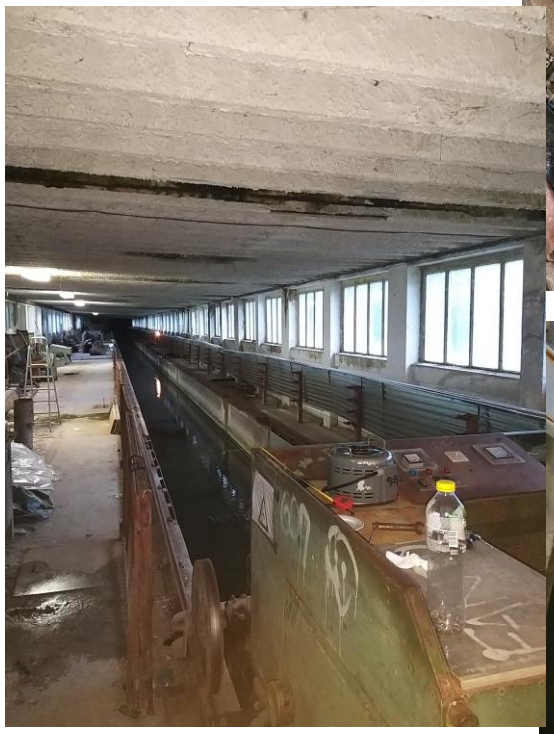
$$Q = A \cdot V_{sr}$$

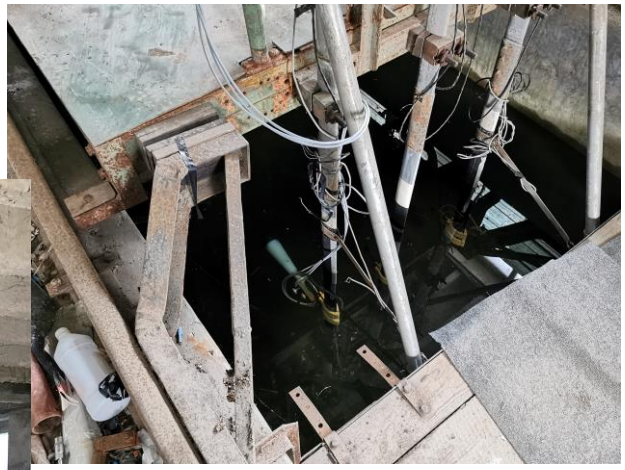
$$V_{et} = V_{sr}$$

PRIMERI

1. Kalibracija EM senzora brzine

$$V_{et} = V$$

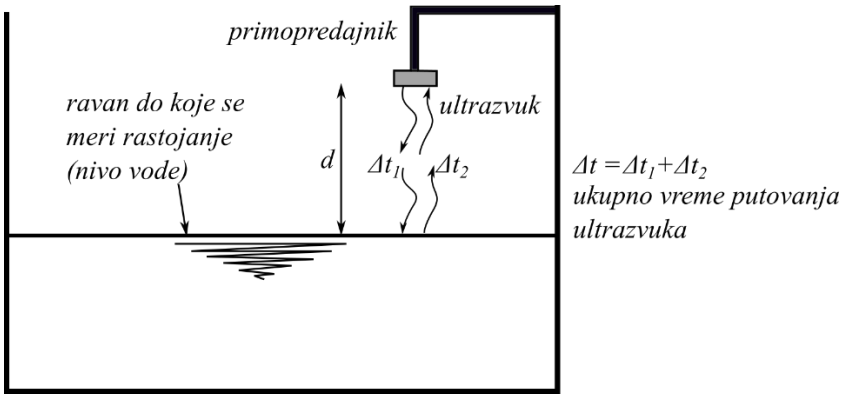




PRIMERI

2. Kalibracija ultrazvučnog senzora nivoa (odstojanja)

$$d[m] = c\left[\frac{m}{s}\right] \cdot \frac{\Delta t[s]}{2} \qquad H[m] = f(\Delta t[s])$$



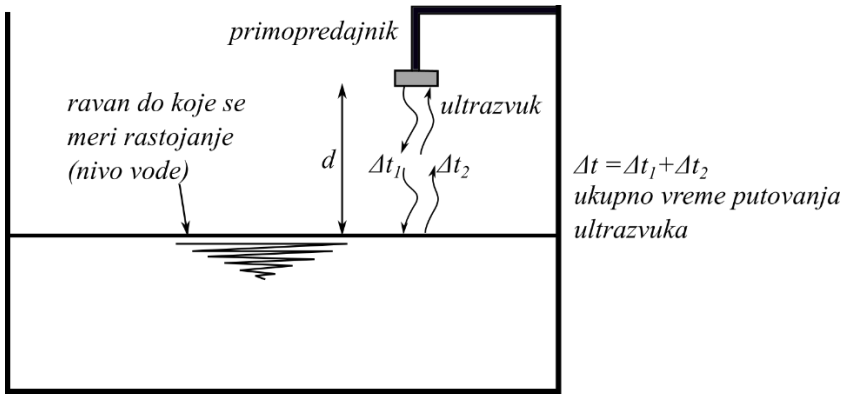
U okviru vežbe ćemo kalibrisati tako da odredimo vezu između Δt **i** d.

$$H = H_0 + (c\frac{\Delta t_0 - \Delta t_i}{2})$$

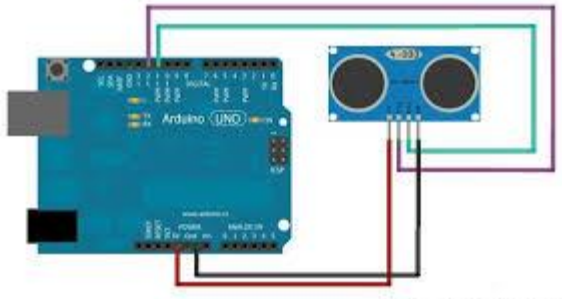
PRIMERI

2. Ultrazvučni senzor – Arduino

$$d[m] = c\left[\frac{m}{s}\right] \cdot \frac{\Delta t\,[s]}{2}$$



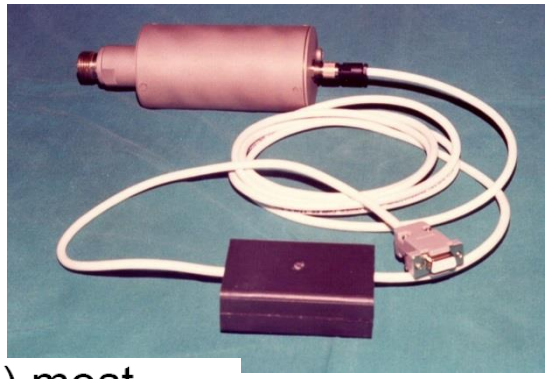
$\Delta t = \Delta t_1 + \Delta t_2$
ukupno vreme putovanja ultrazvuka

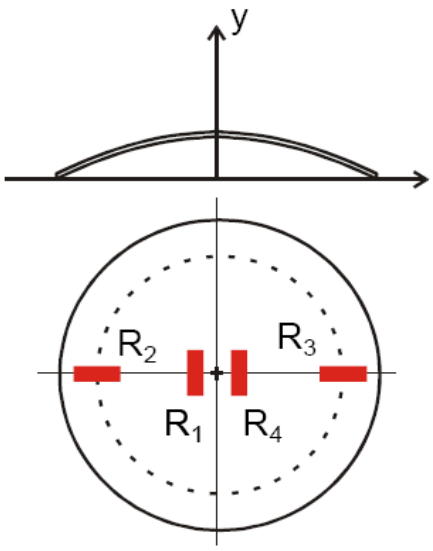


PRIMERI

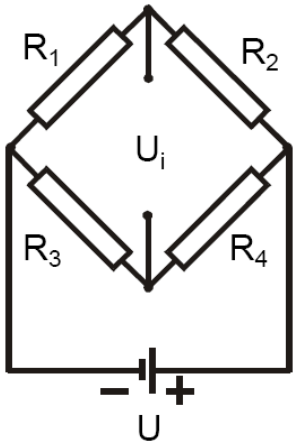
3. Pijezorezistivni senzor – AP02

$$p[bar] = f(U[V])$$





Vitstonov (Wheatstone) most



most je u ravnoteži kada je odnos otpornosti:

$$R_1 \cdot R_4 = R_2 \cdot R_3 \qquad U_{izl} = E \cdot \frac{R_1 \cdot R_4 - R_2 \cdot R_3}{(R_1 + R_2) \cdot (R_3 + R_4)} = 0$$

PRIMERI

3. Pijezorezistivni senzor – AP02

$$p[bar] = f(U[V])$$

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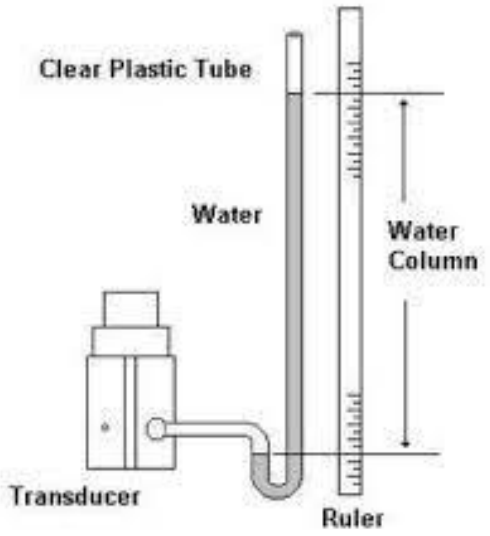
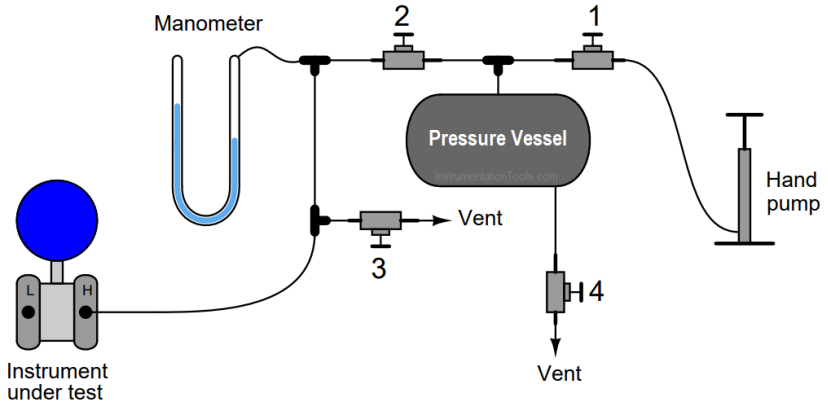
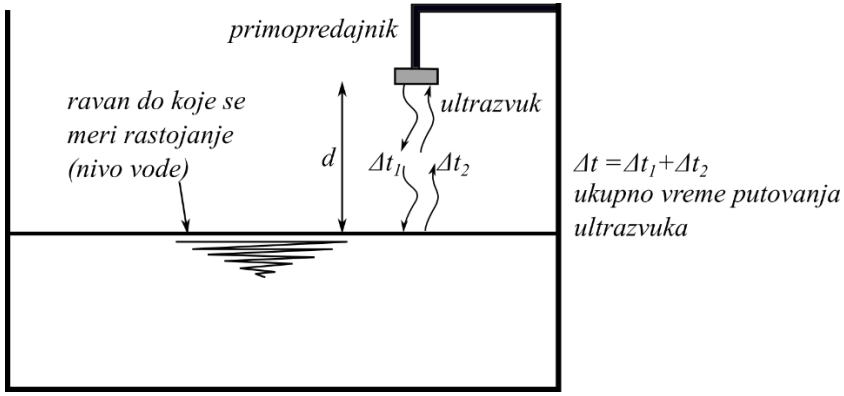




PRIMERI

2. Ultrazvučni senzor – Arduino

$$d[m] = c\left[\frac{m}{s}\right] \cdot \frac{\Delta t\,[s]}{2}$$



$\Delta t = \Delta t_1 + \Delta t_2$
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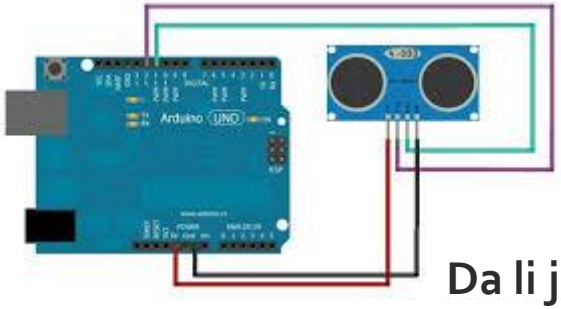
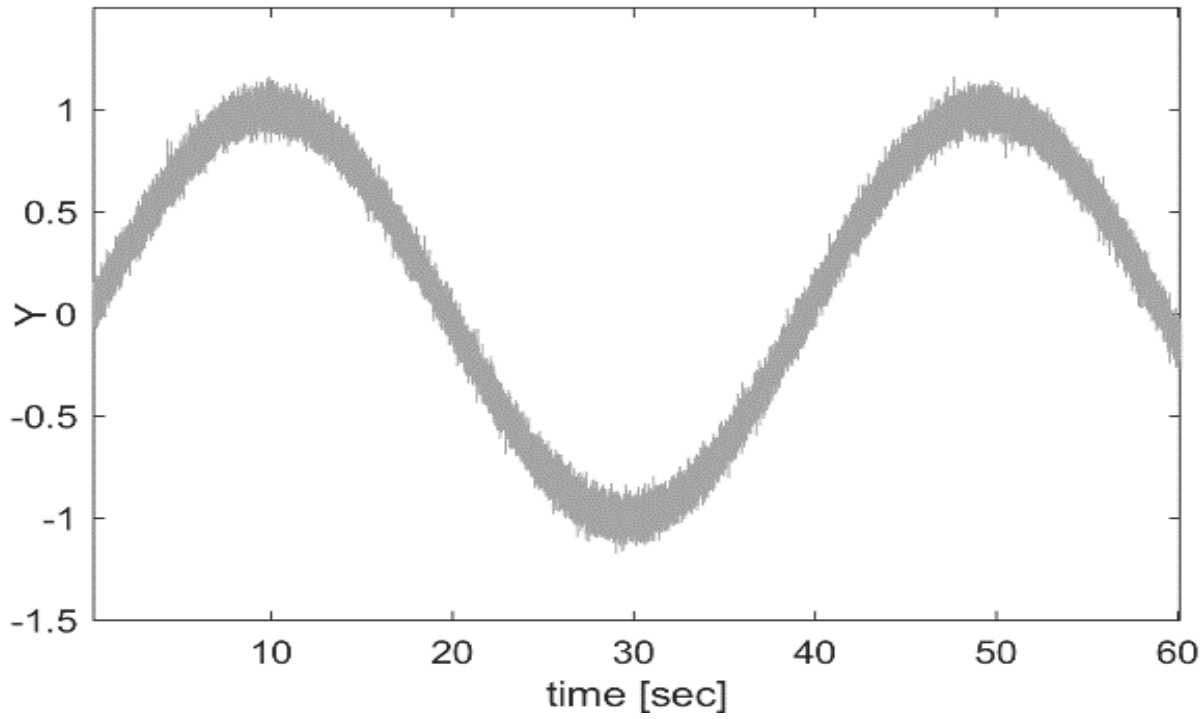


Da li je ovo lak posao?

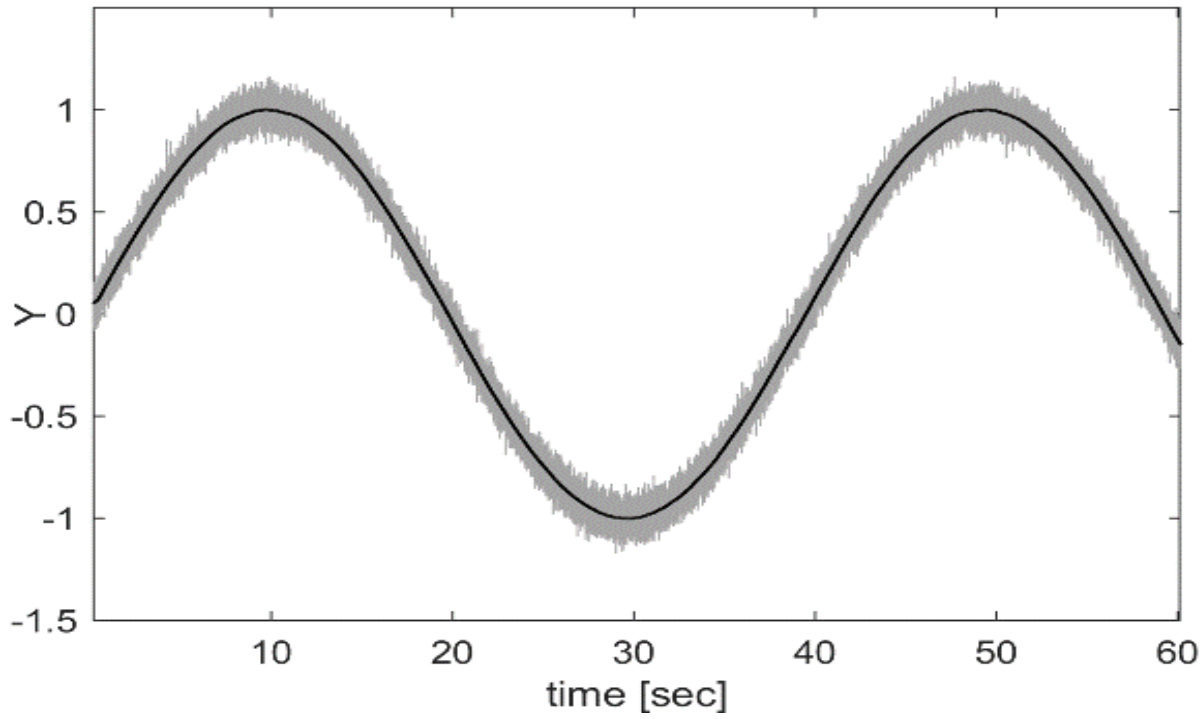
OBRADA SIGNALA

Šum



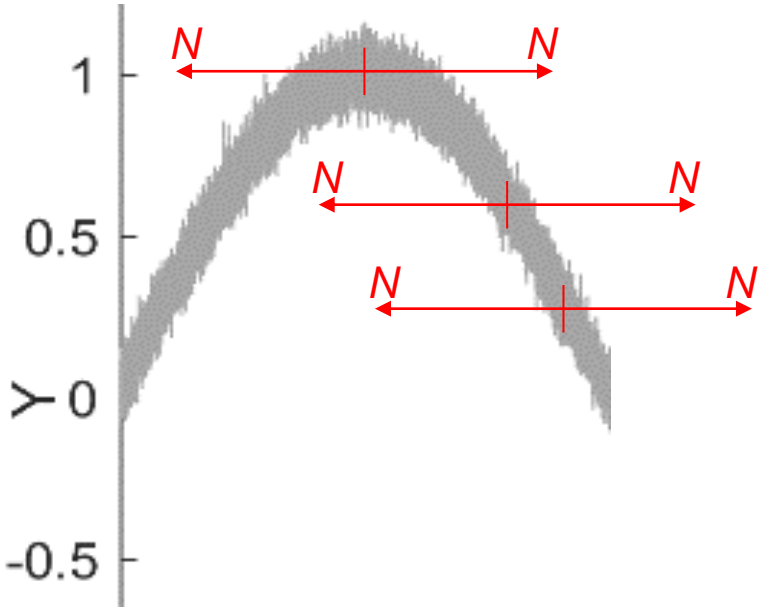
OBRADA SIGNALA

Filter



OBRADA SIGNALA

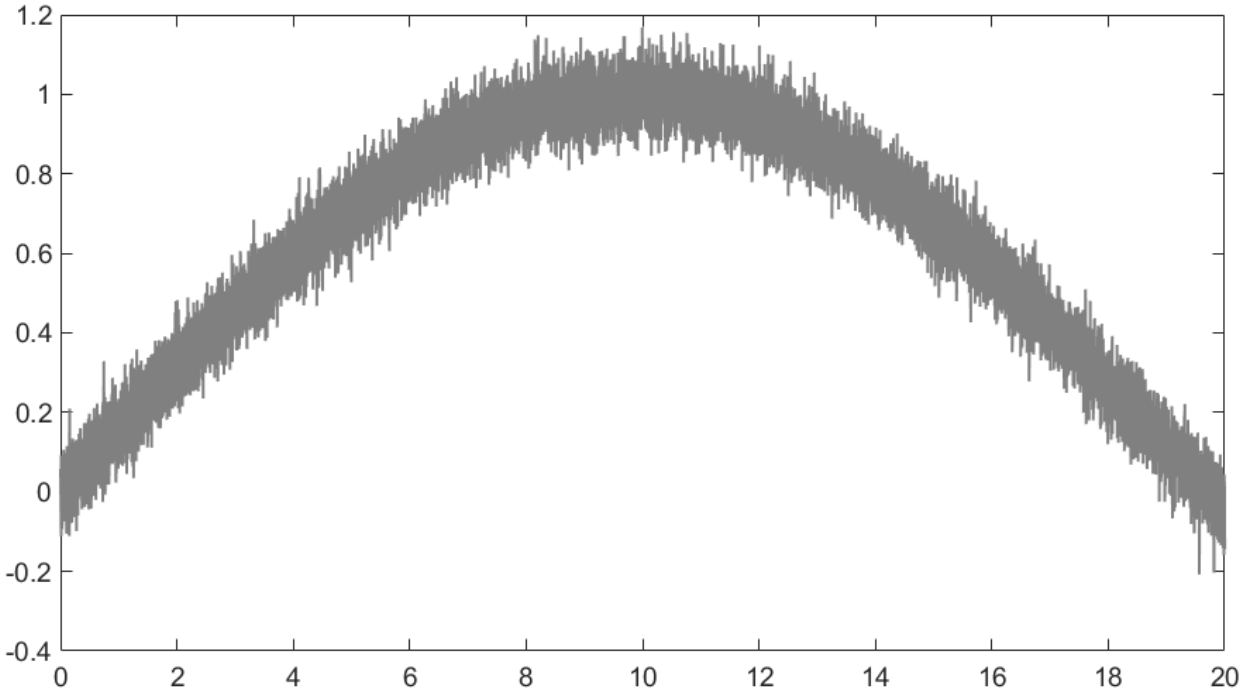
(Central) Moving Average filter – Putujuća srednja vrednost



$$\overline{p_i} = \frac{p_{i-N} + p_{i-N+1} + \cdots + p_i + \cdots + p_{i+N-1} + p_{i+N}}{2N}$$

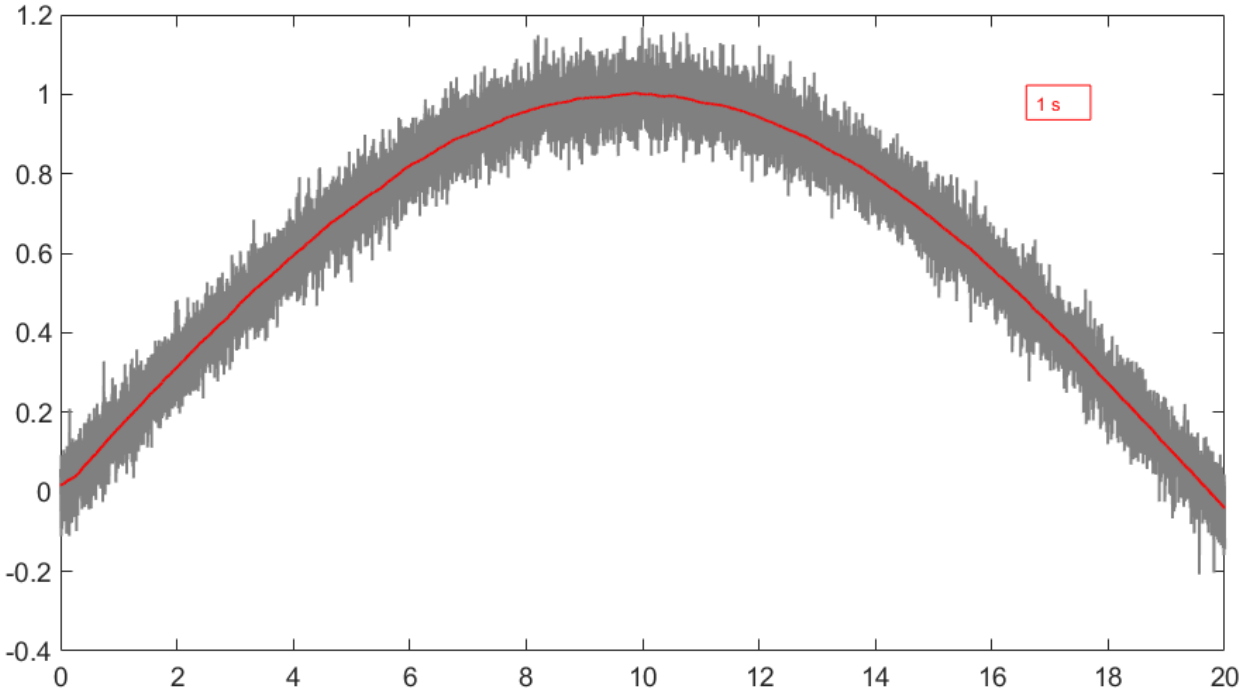
OBRADA SIGNALA

Moving Average filter – Primer



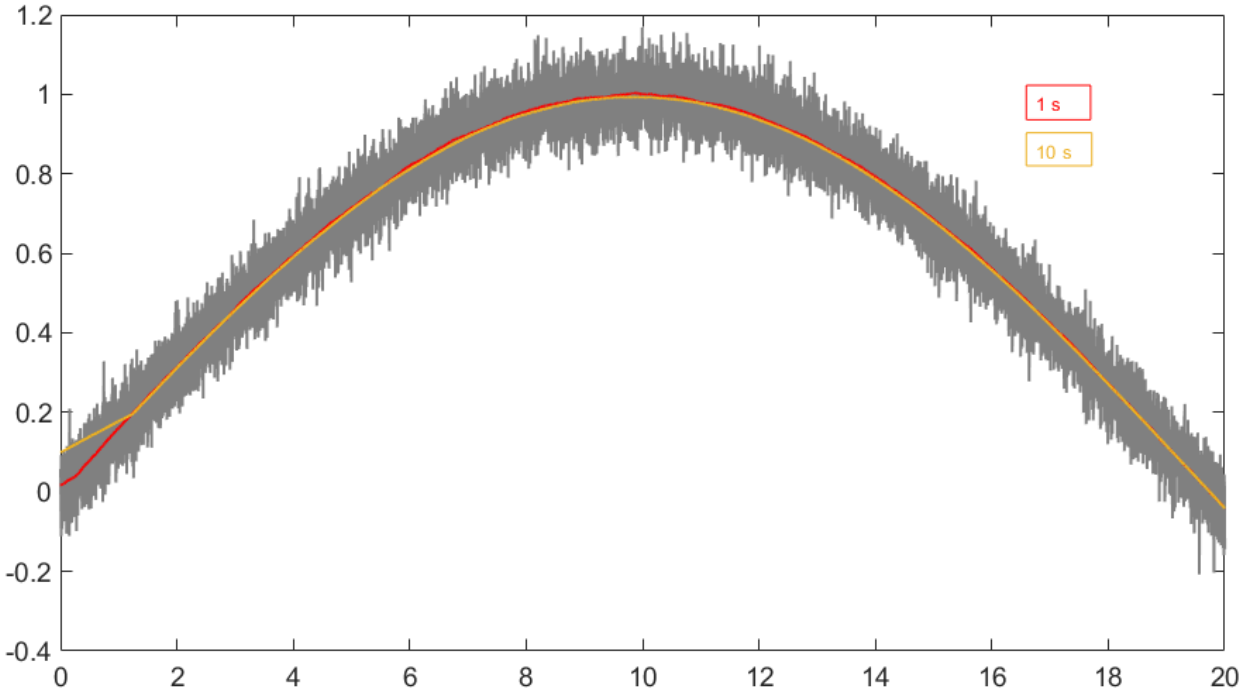
OBRADA SIGNALA

Moving Average filter – Primer



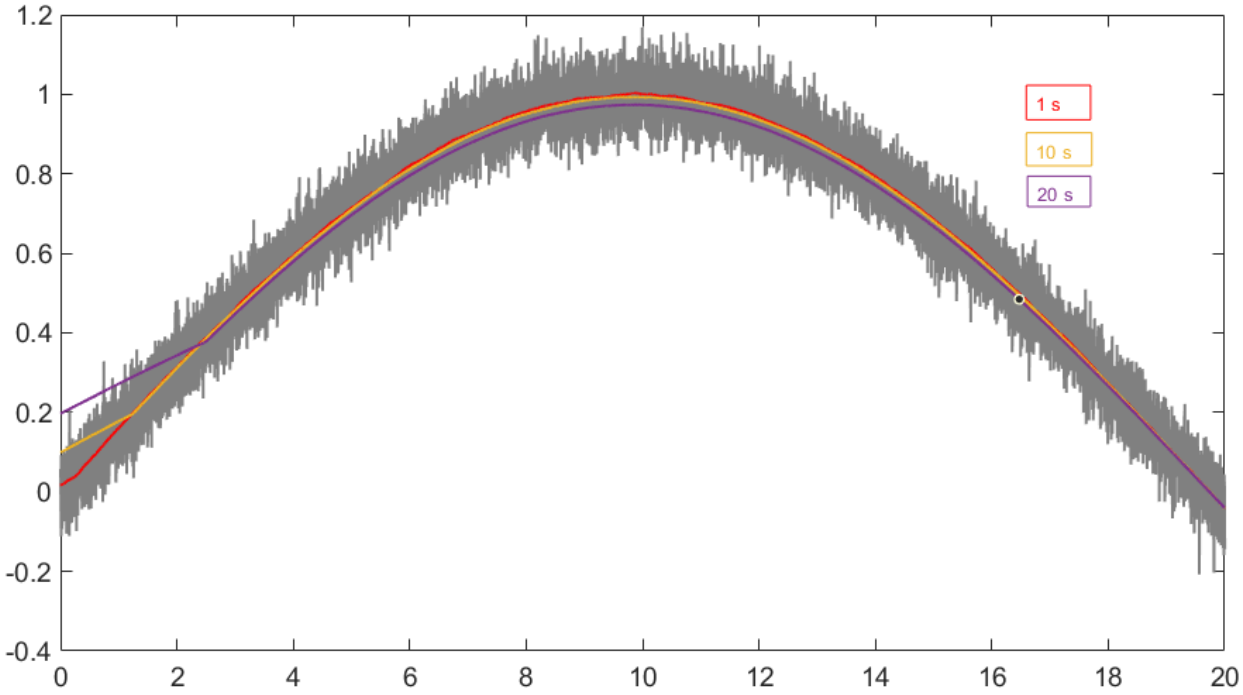
OBRADA SIGNALA

Moving Average filter – Primer



OBRADA SIGNALA

Moving Average filter – Primer

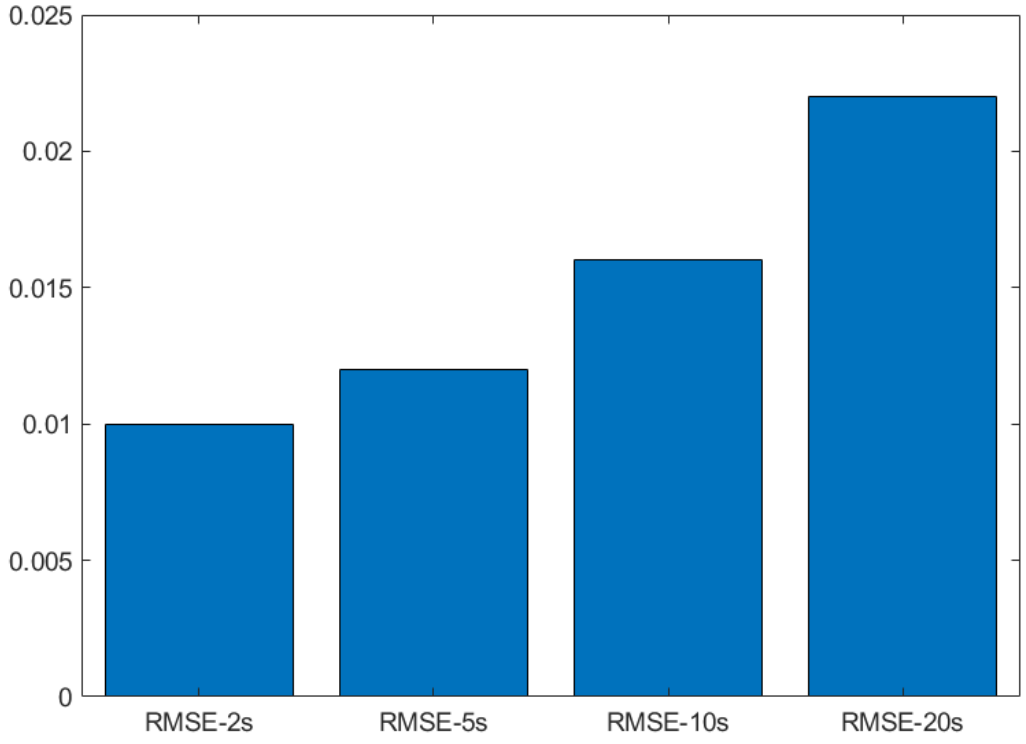


OBRADA SIGNALA

Poredjenje vremenskih serija – Root Mean Square Error *RMSE*

Osrednjavanje na 1s se usvaja kao referentno

$$RMSE = \sqrt{\frac{\sum_{i=1}^{N} \left(X_{ref,i} - X_i\right)^2}{N}}$$



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