

# Lidarski sistem z več vidnimi polji za zagotavljanje varnosti v robotiki

ZAGOVOR DOKTORSKE DISERTACIJE

Luka Pogačnik

Mentor: prof. dr. Marko Munih

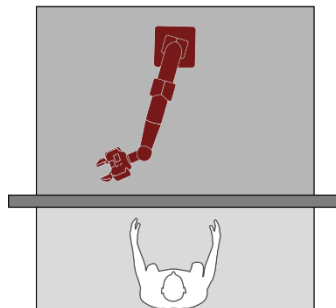
Ljubljana, 16. 9. 2024

# Vsebina

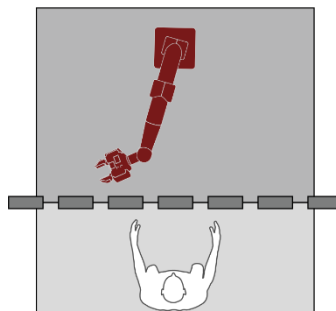
- Motivacija
  - Stanje tehnike
  - Predlog izboljšave
- Preusmerjanje enega vidnega polja
  - Analiza delovanja
  - Predlog rešitve problema
- Preusmerjanje več vidnih polij
  - Analiza delovanja
  - Predlog rešitve problema
- Zaznavanje nepričakovanega posega v robotov delovni prostor
  - Zasnova algoritma za primerjavo trenutnih meritev z referenčnimi vrednostmi
  - Analiza delovanja v več scenarijih

# Interakcija človeka z robotom

**Primer 1:** Popolna ločitev  
*Fiksna zaščitna ograja*

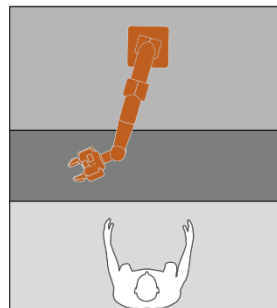


**Primer 2:** Virtualna ločitev  
*Virtualna zaščitna ograja*

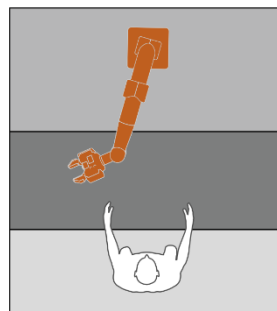


**POPOLNA AVTOMATIZACIJA**  
Industrijski/sodelujoč robot  
*Stik ni dovoljen*

**Primer 3:** Deljen delovni prostor  
*Varnostno nadzorovana ustavitev*

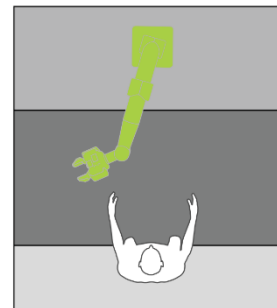


**Primer 4:** Deljen delovni prostor  
*Nadzor hitrosti in varnostne razdalje*

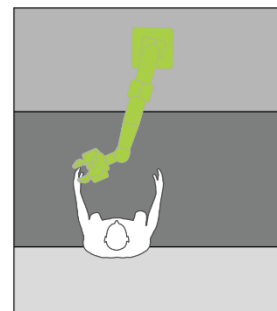


**KOOPERACIJA**  
Industrijski/sodelujoč robot  
*Stik dovoljen samo v mirovanju*

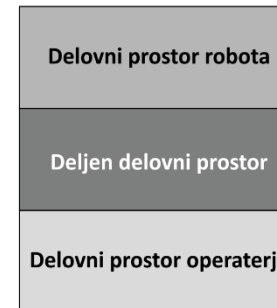
**Primer 5:** Deljen delovni prostor  
*Omejitev moči in sile*



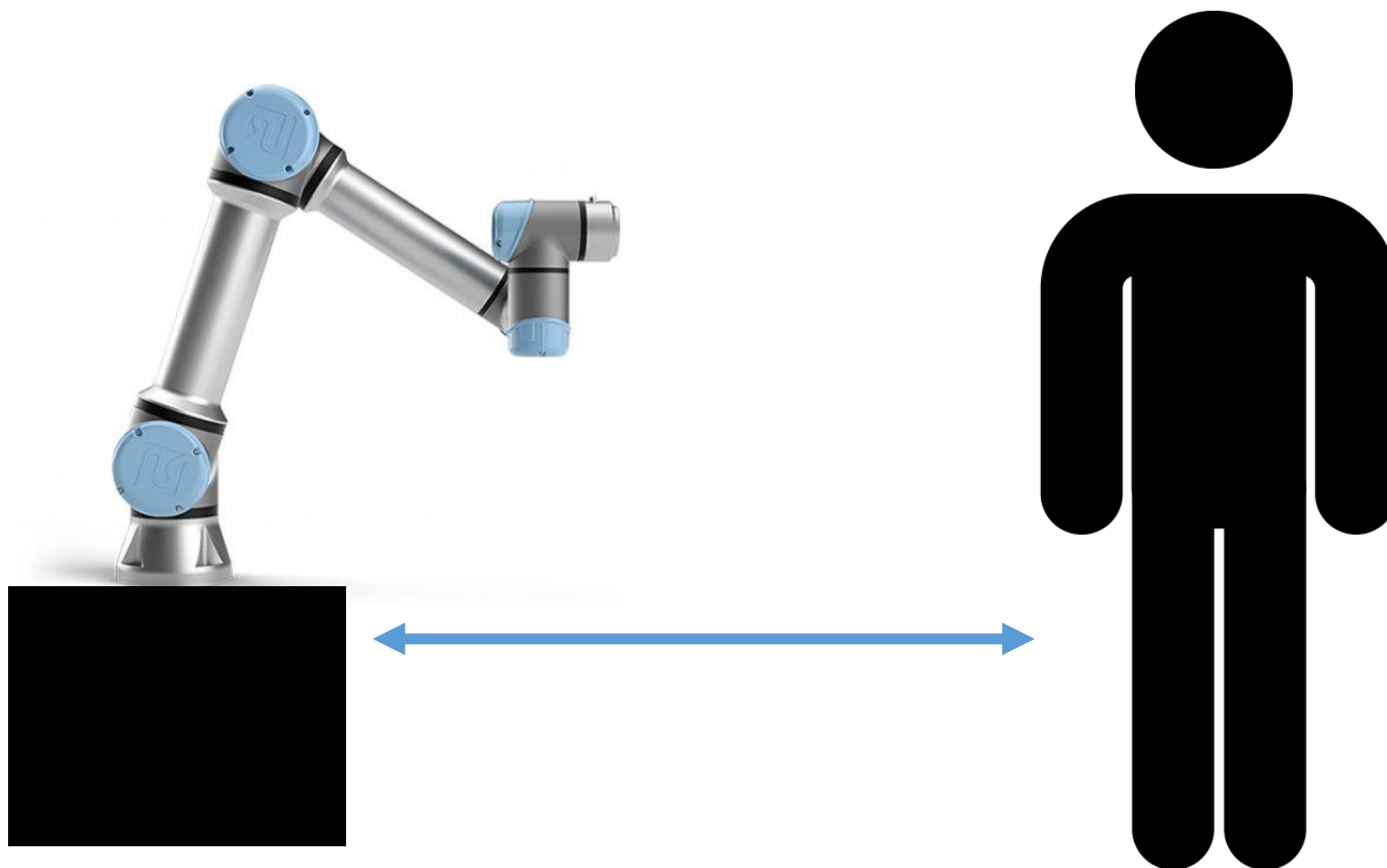
**Primer 6:** Deljen delovni prostor  
*Vodenje z roko*



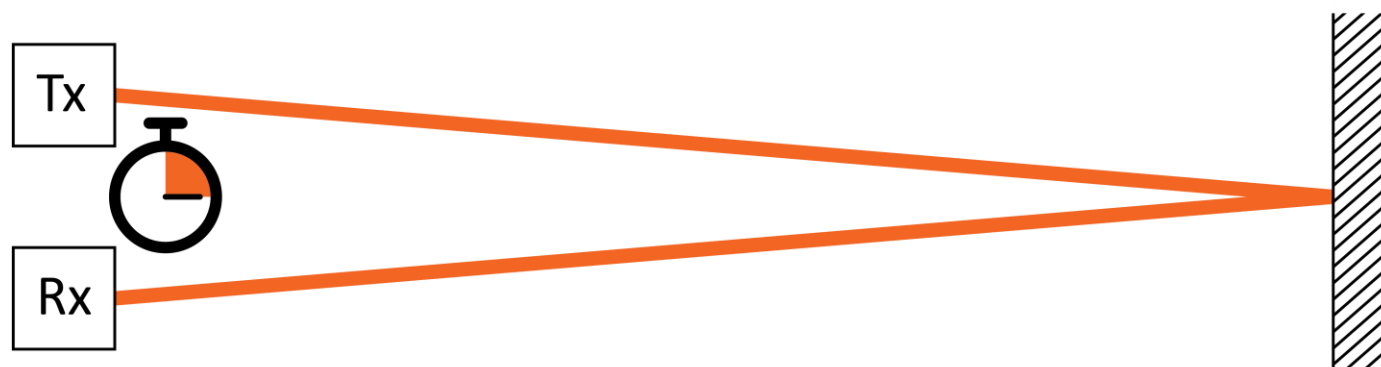
**SODELOVANJE**  
Sodelujoč robot  
*Stik dovoljen, toda brez poškodb*



# Določanje varnostne razdalje

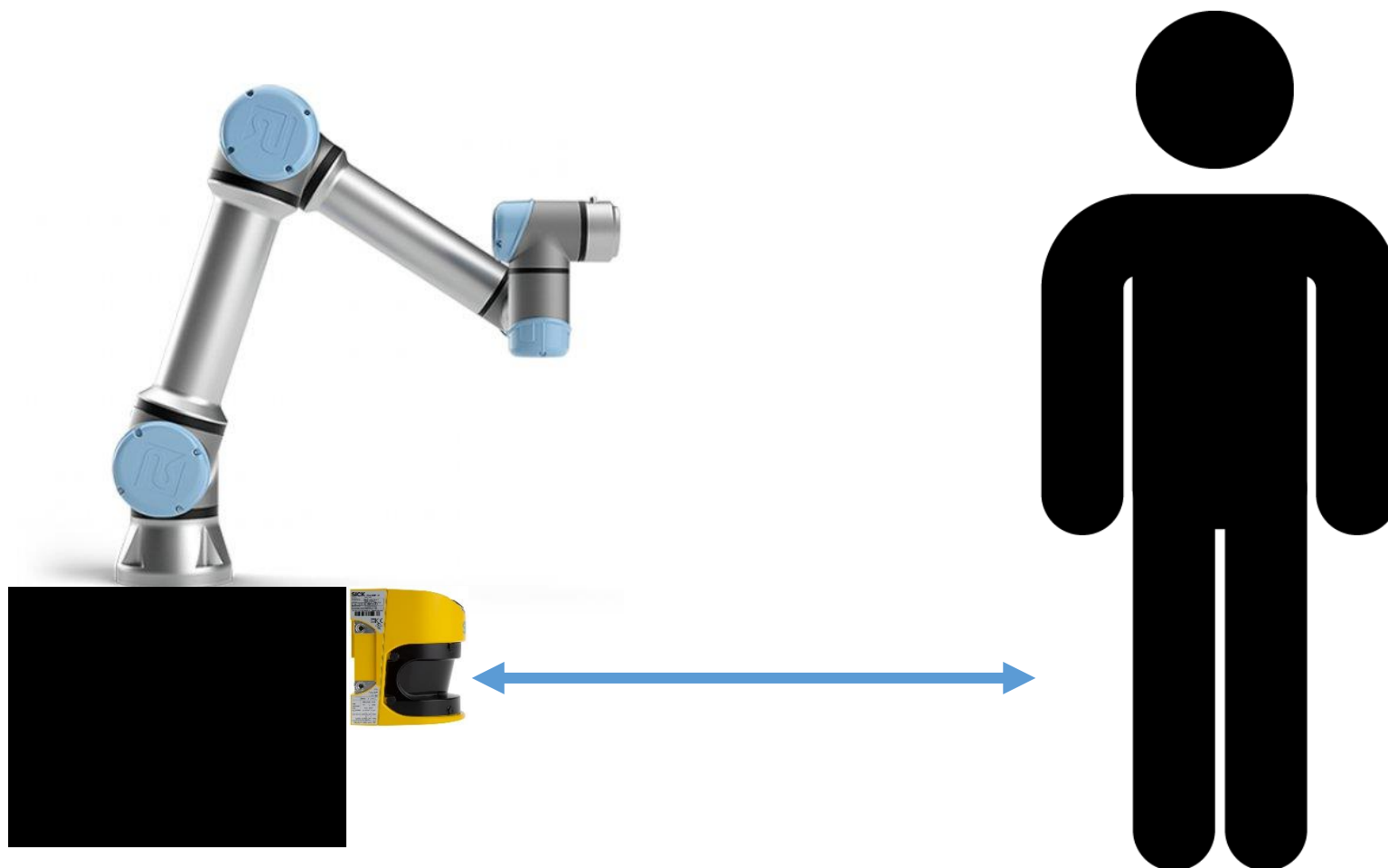


# Določanje varnostne razdalje

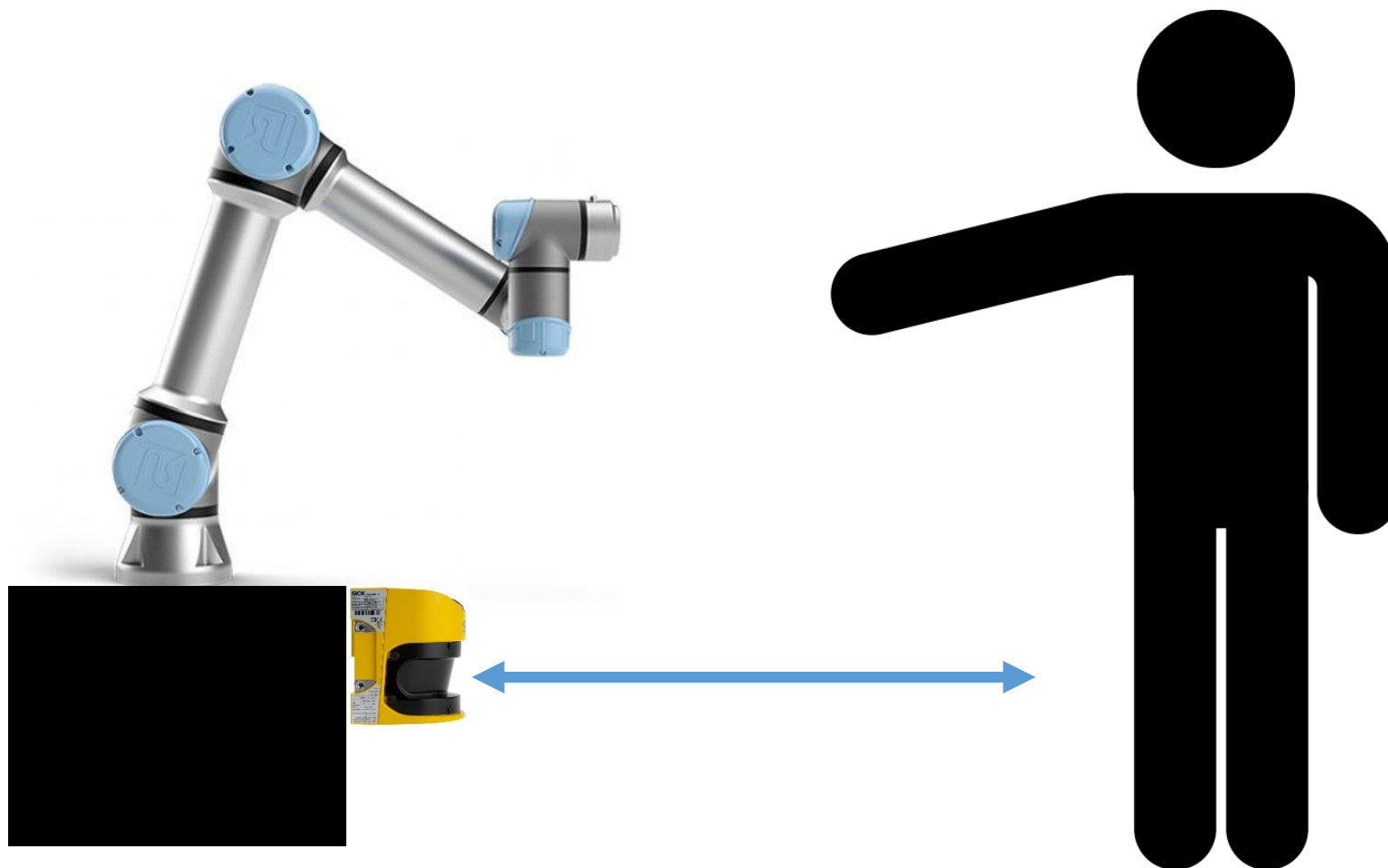


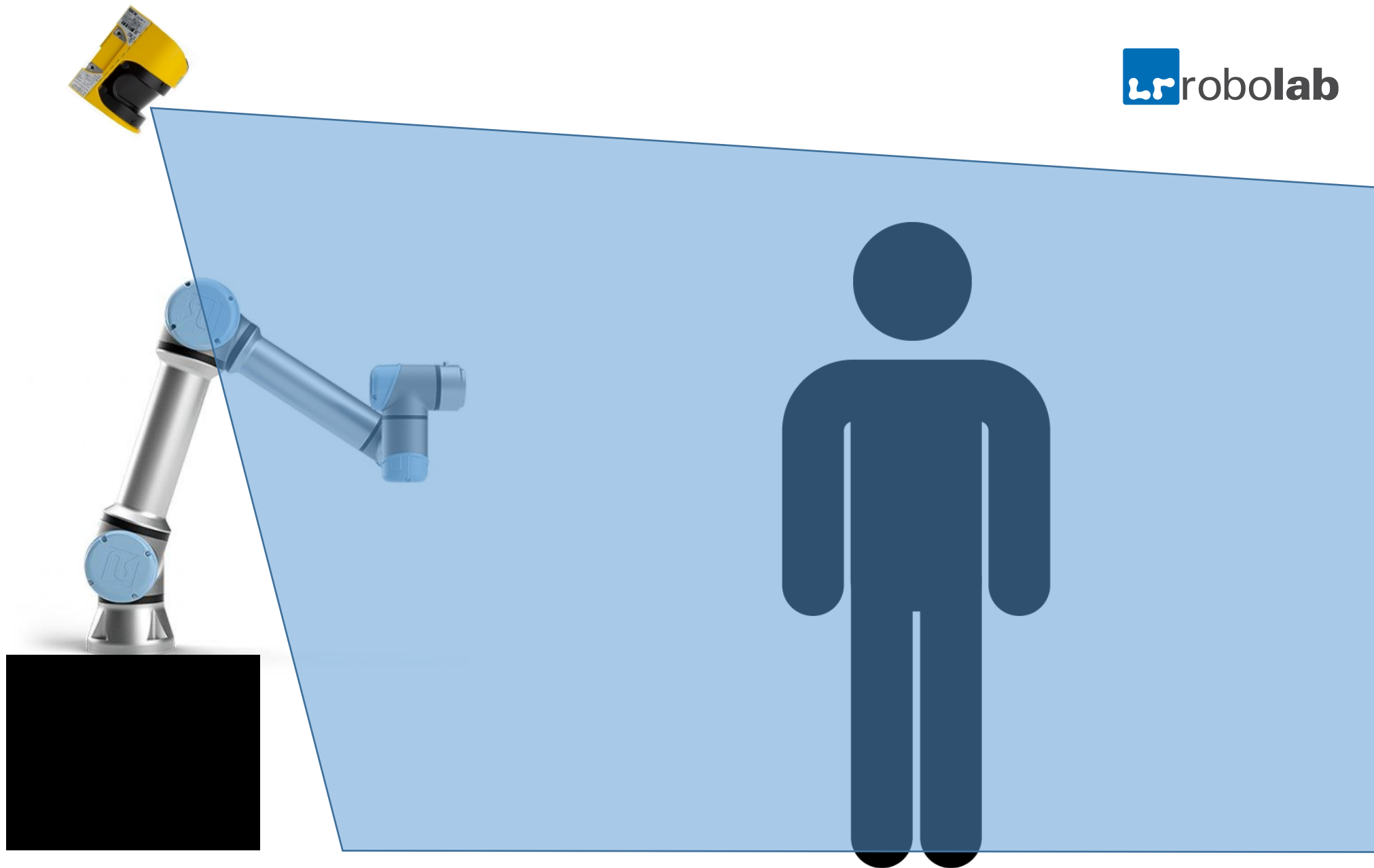
$$s = v \cdot t \rightarrow d = \frac{c \cdot t}{2}$$

# Določanje varnostne razdalje

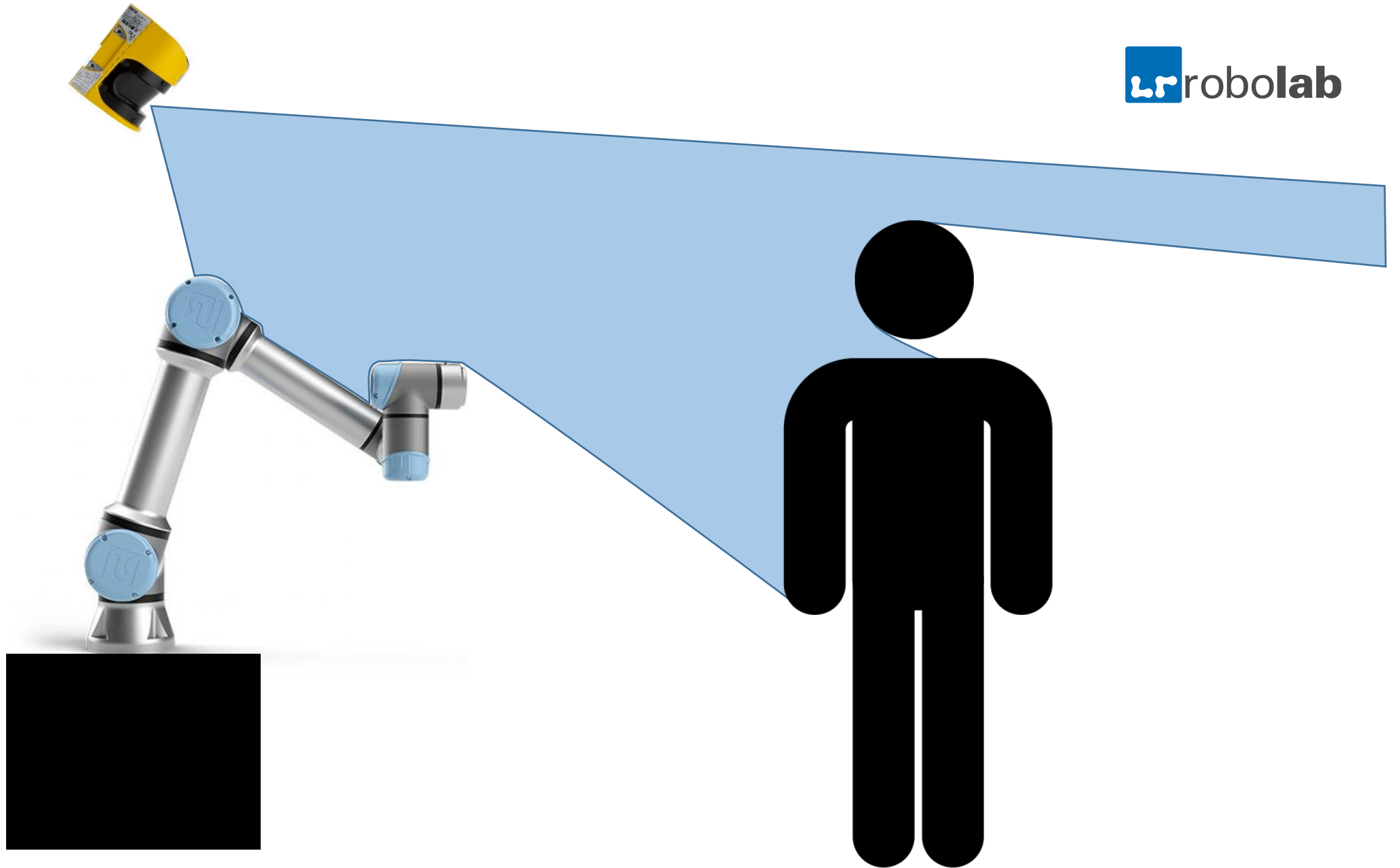


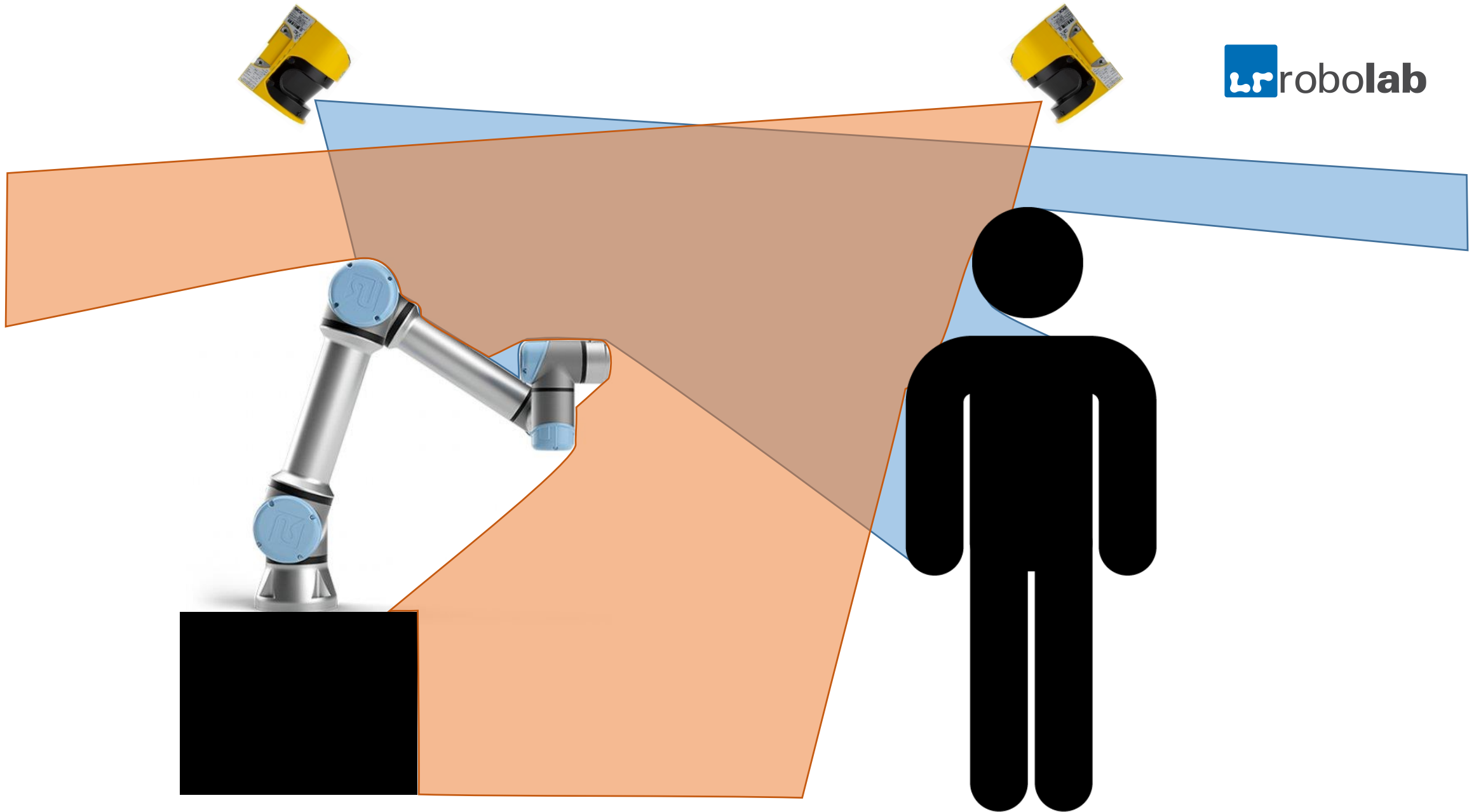
# Določanje varnostne razdalje



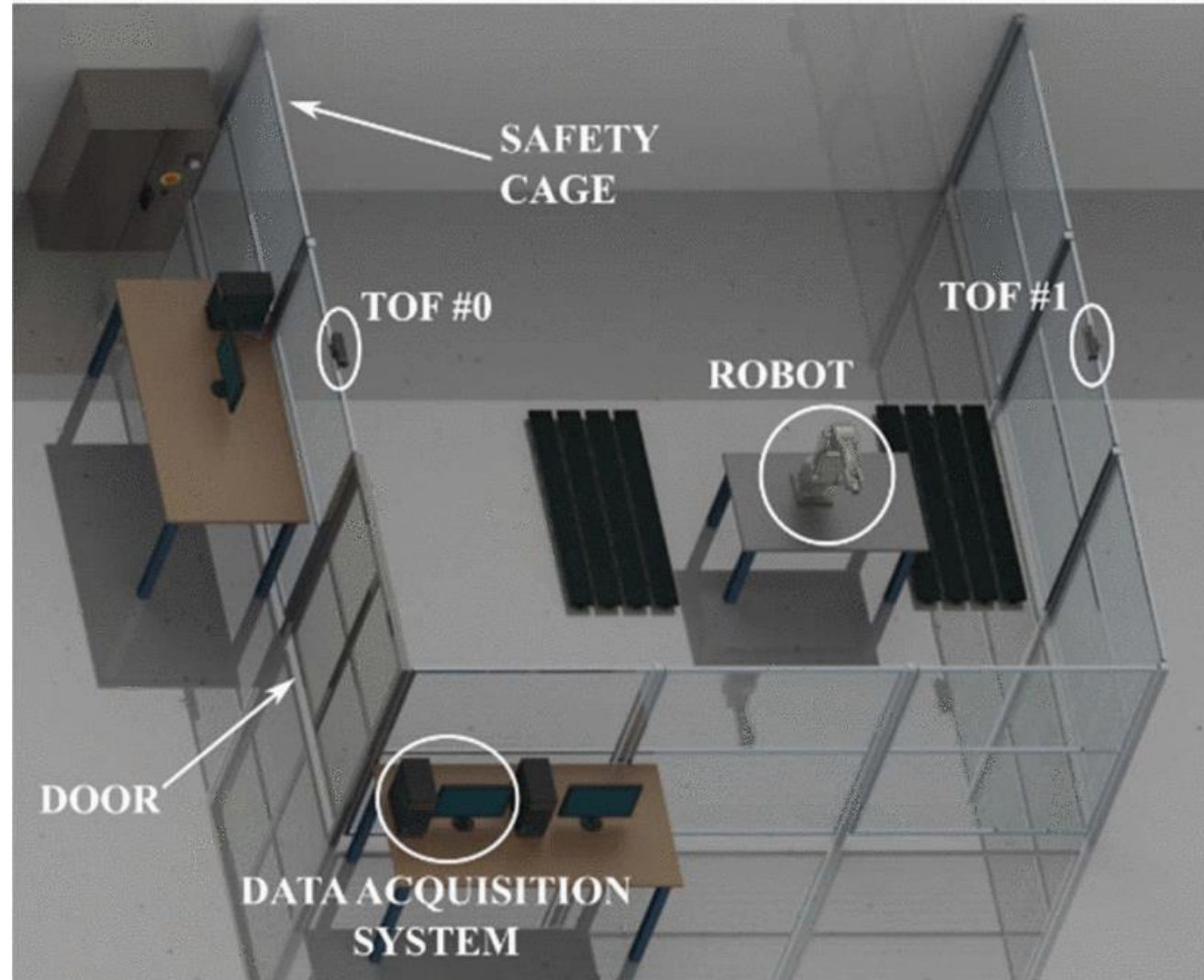




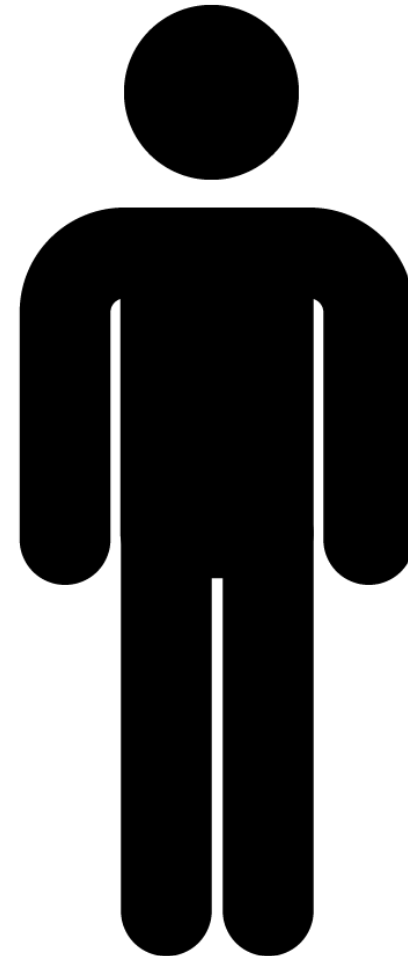
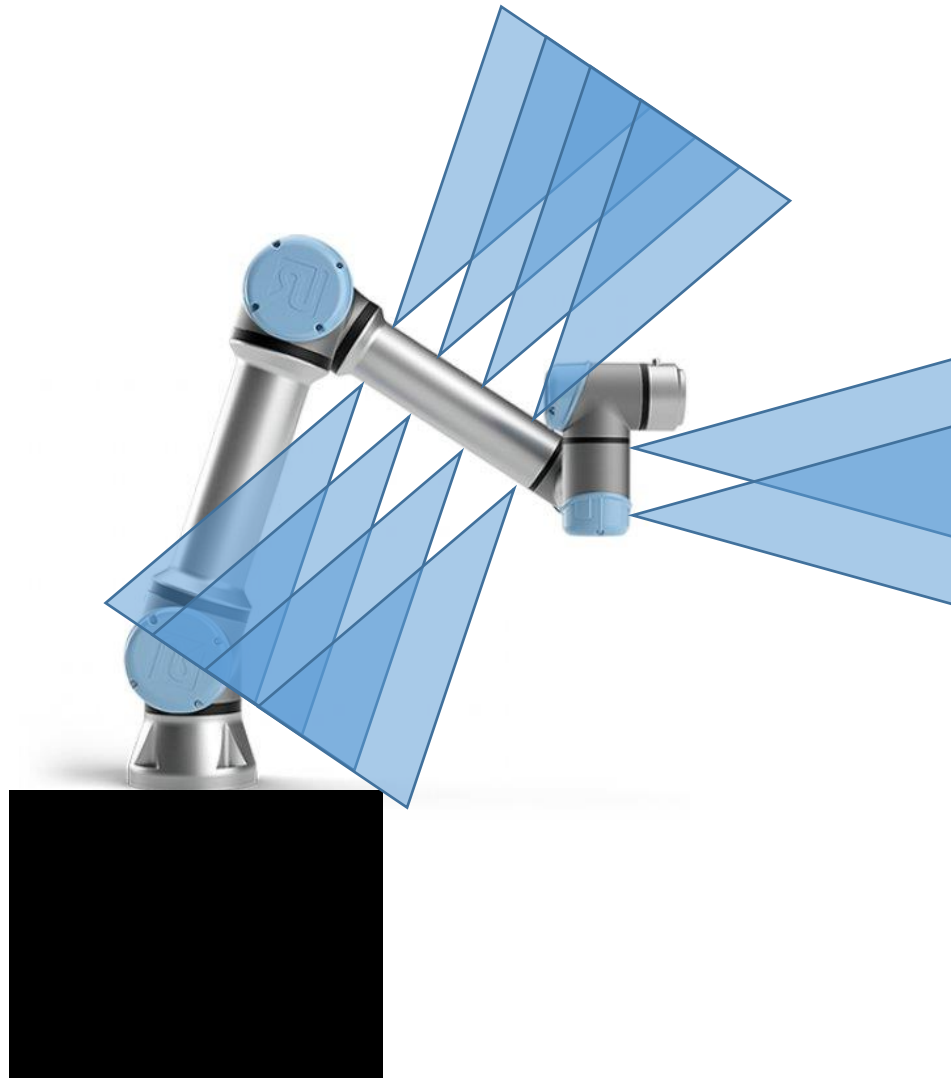




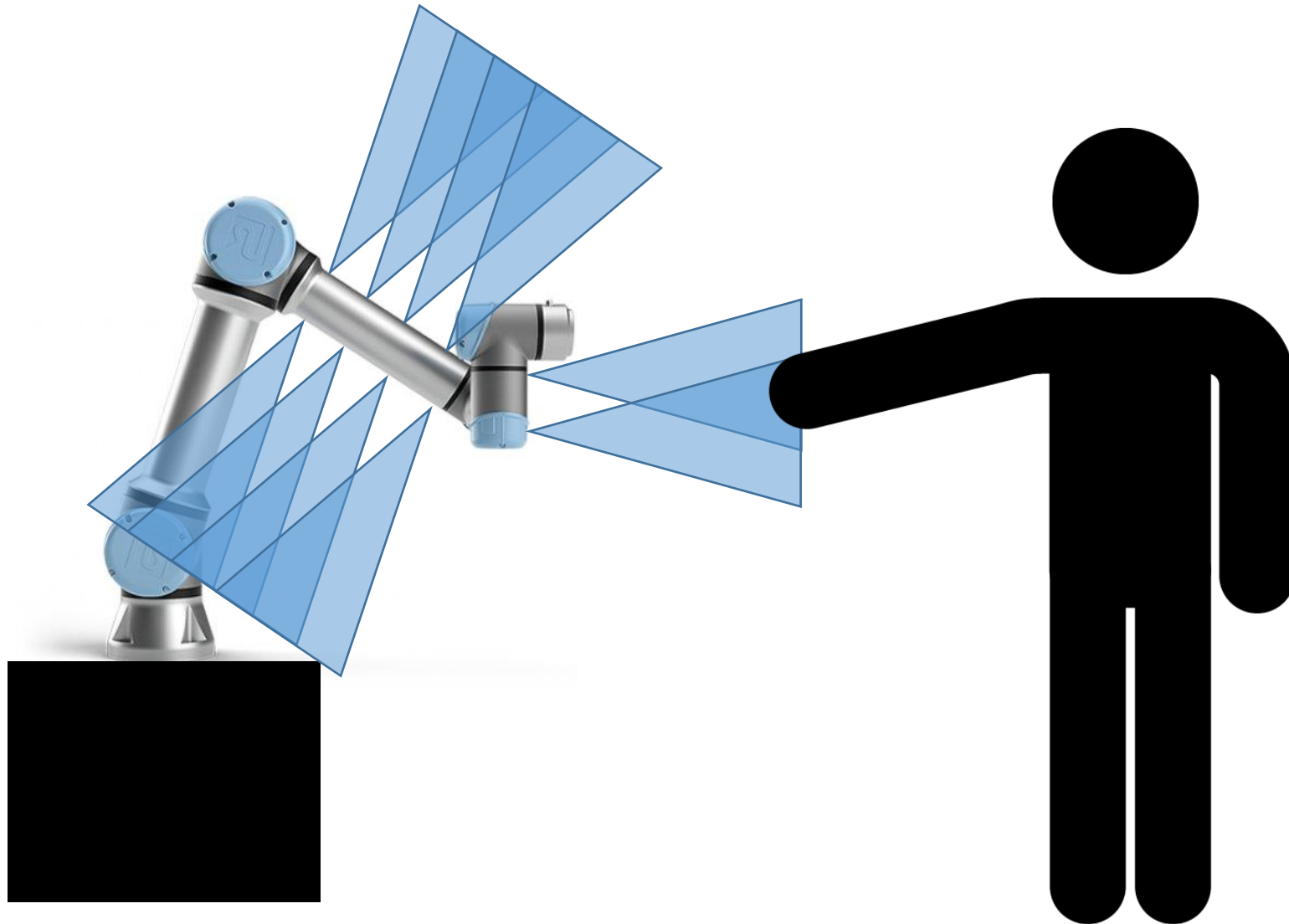
# Pasinetti et. al. - uporaba več globinskih kamer



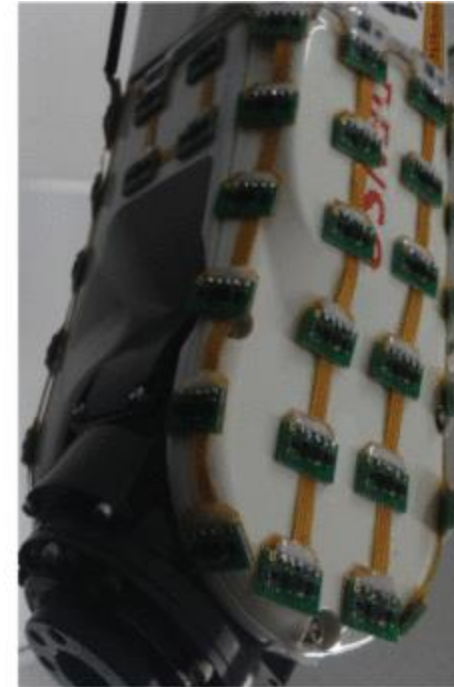
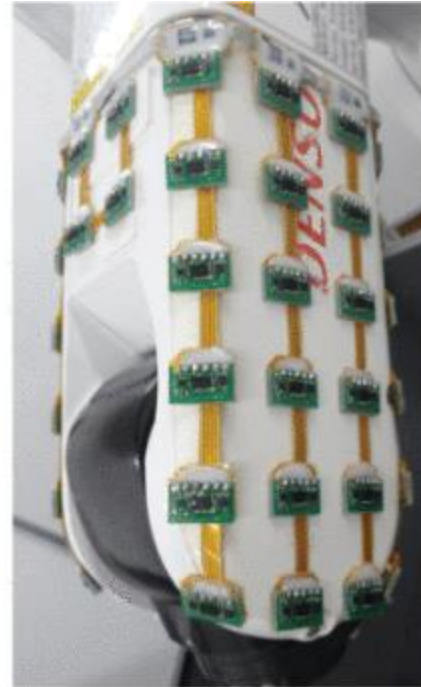
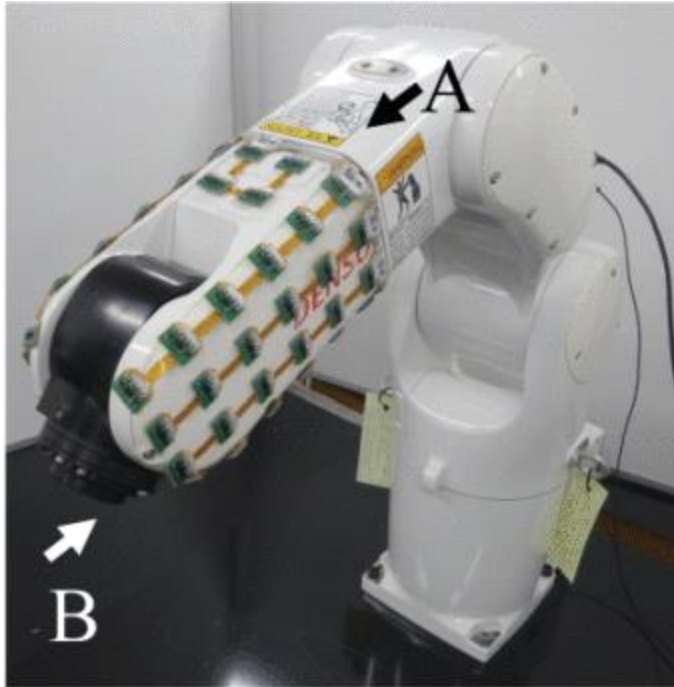
# Opazovanje iz površine robota



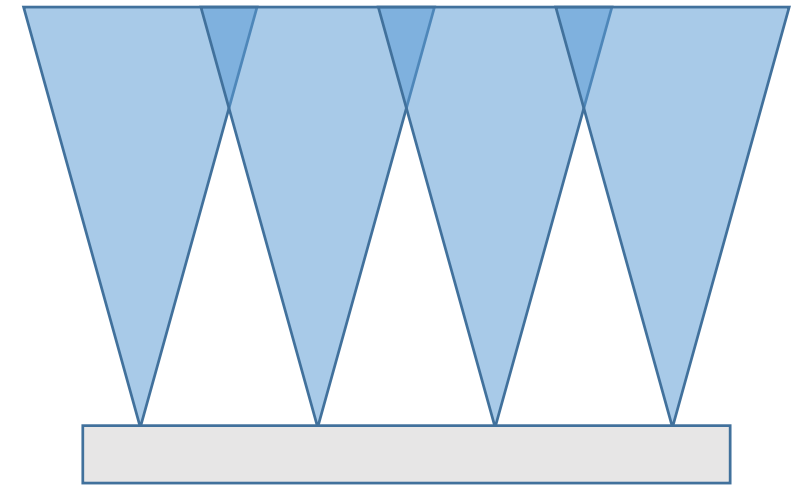
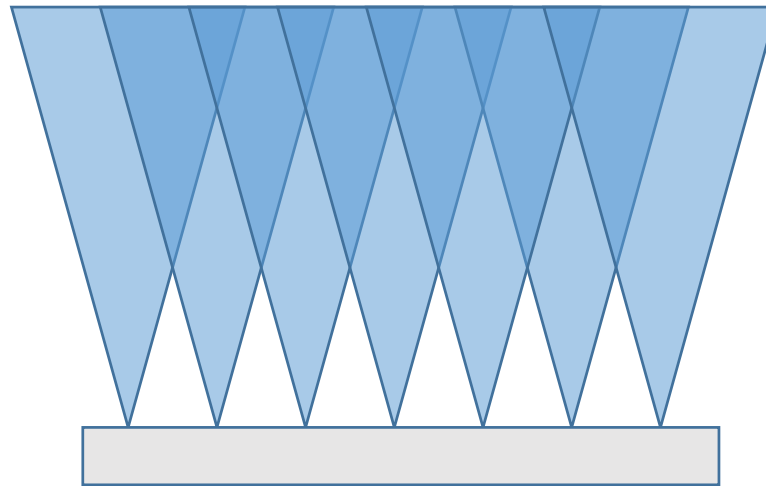
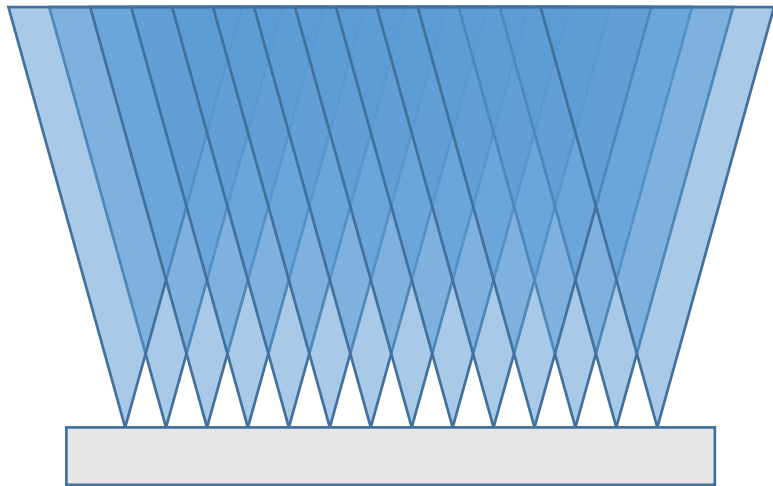
# Opazovanje iz površine robota



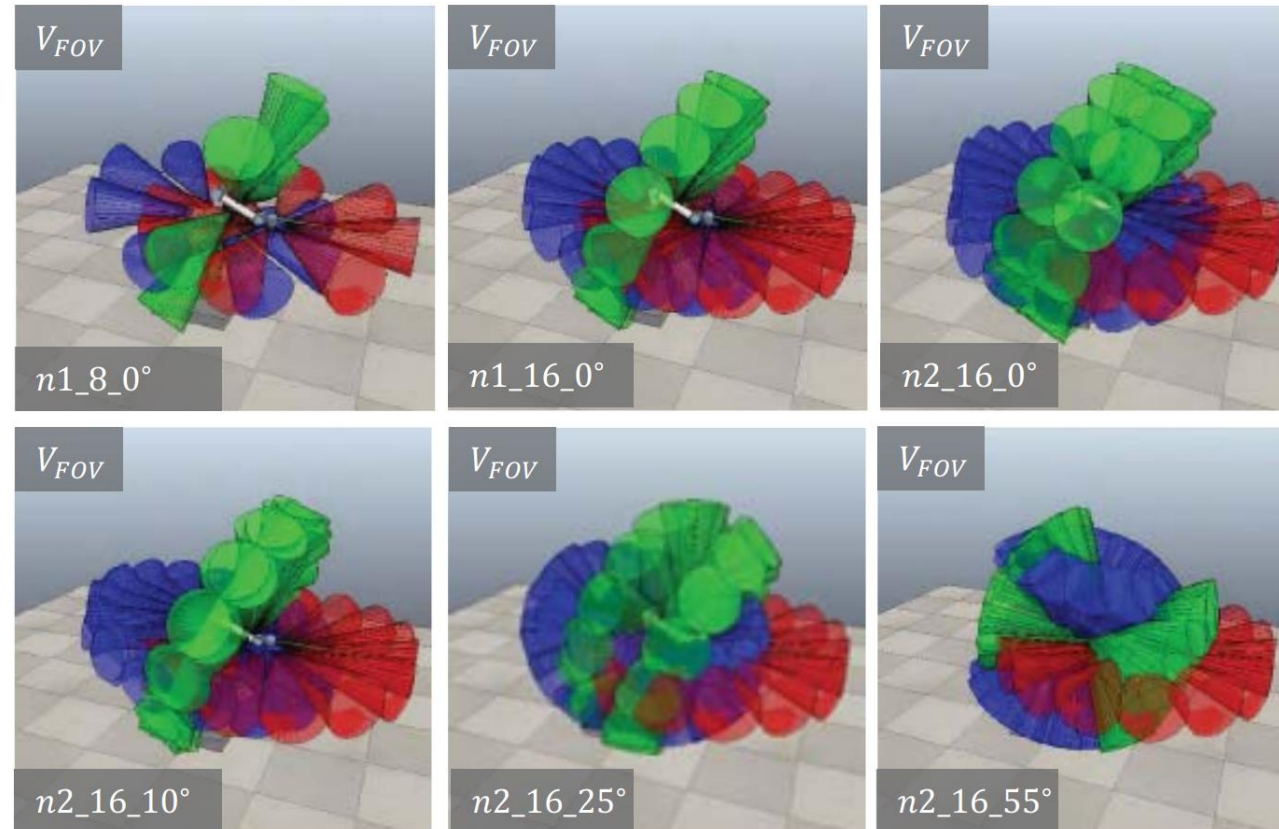
# Tsuji et. al.: opazovanje iz površine robota



# Mrtvo polje ob površini robota

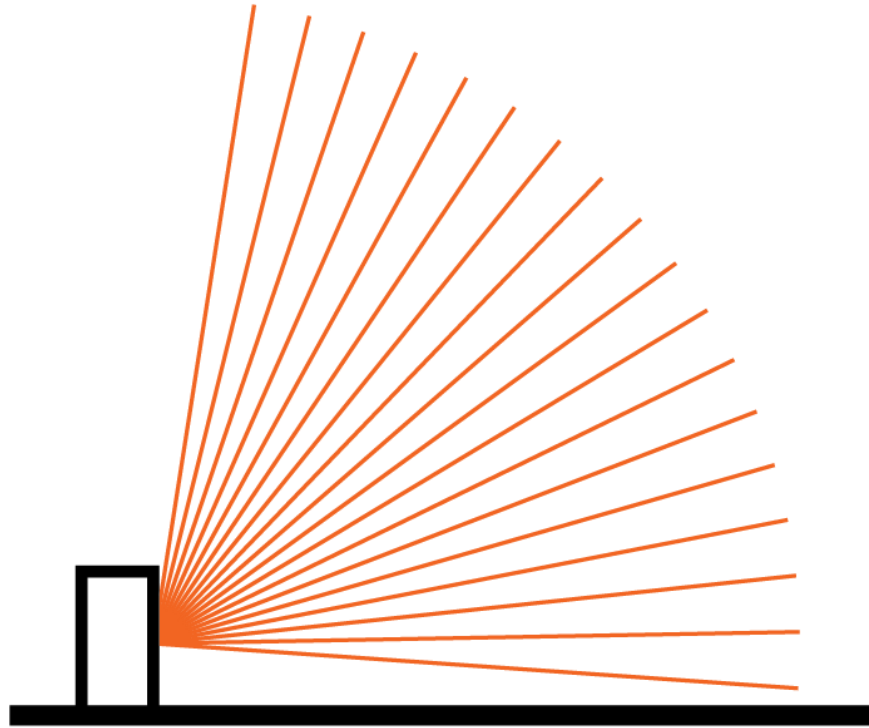


# Adamides et. al.: pokritost okolice

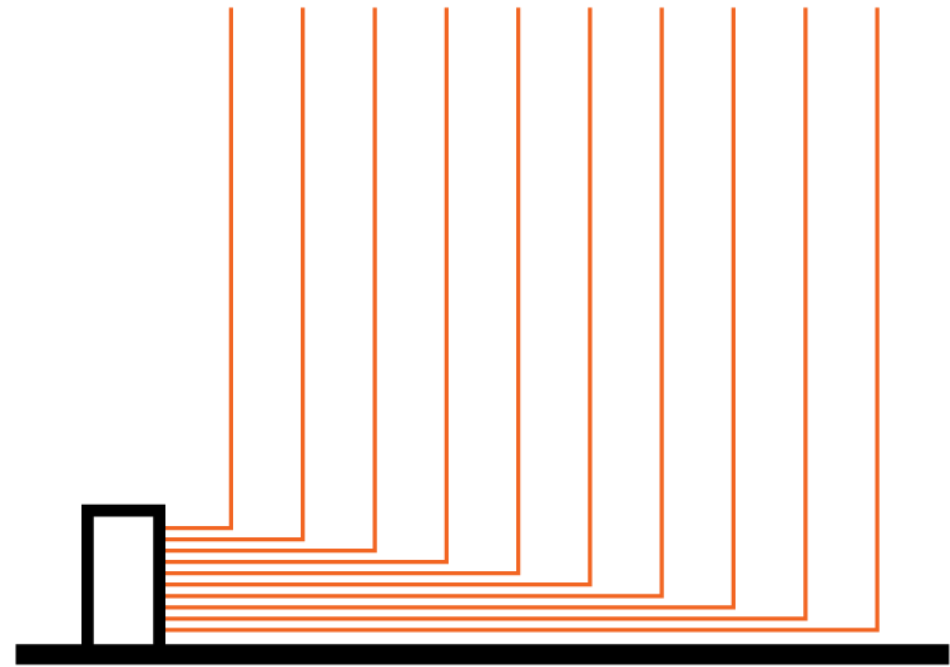
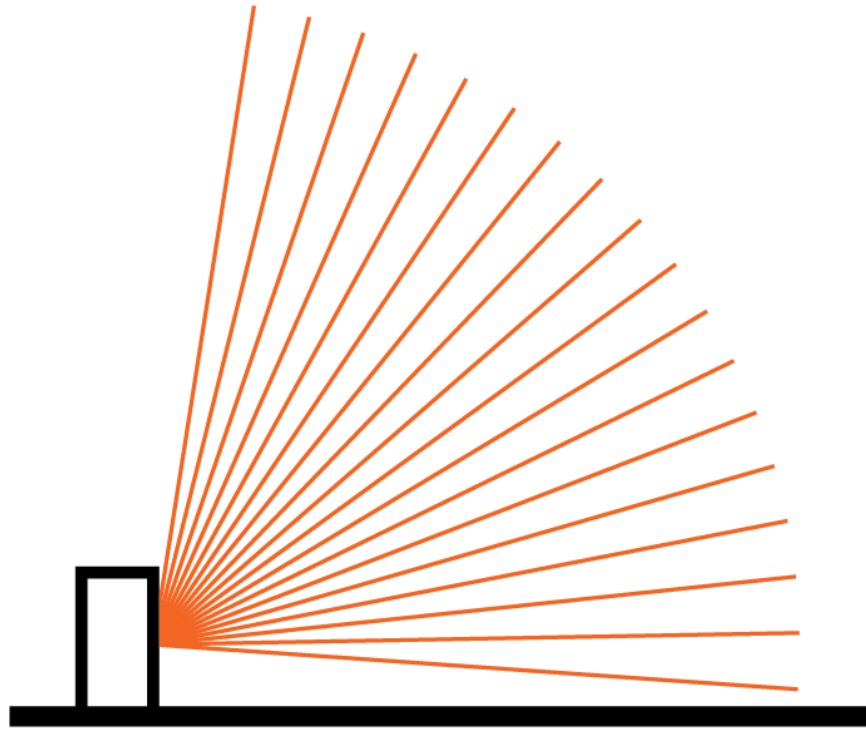




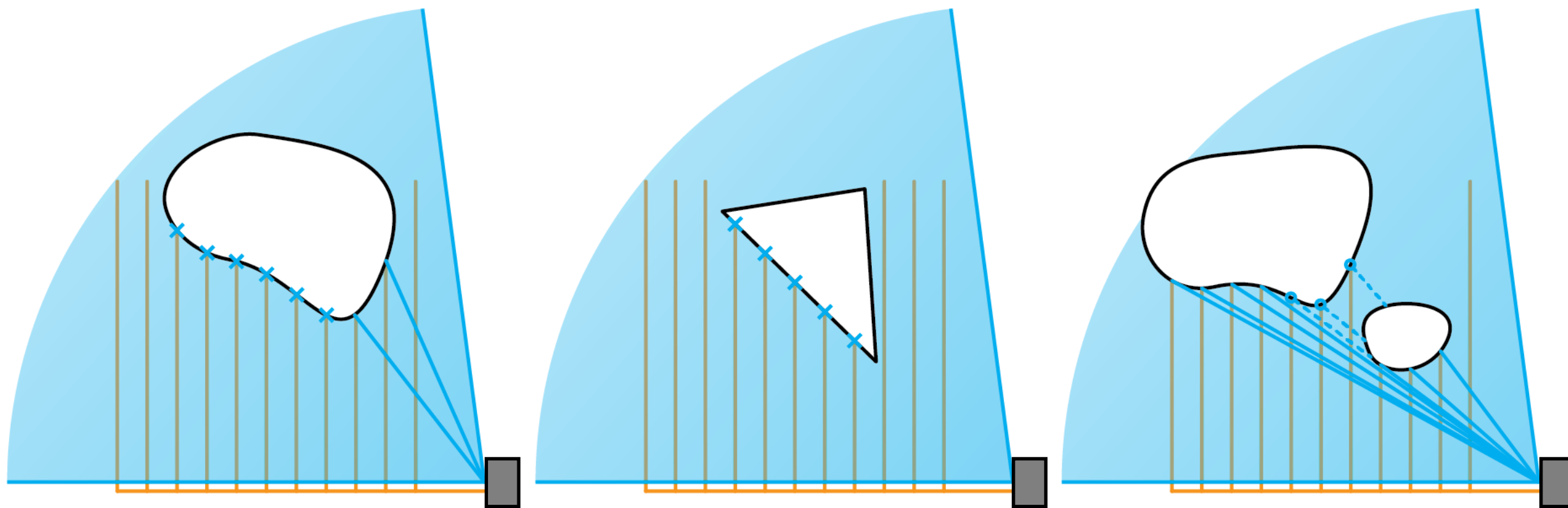
# Primerjava metod preusmerjanja



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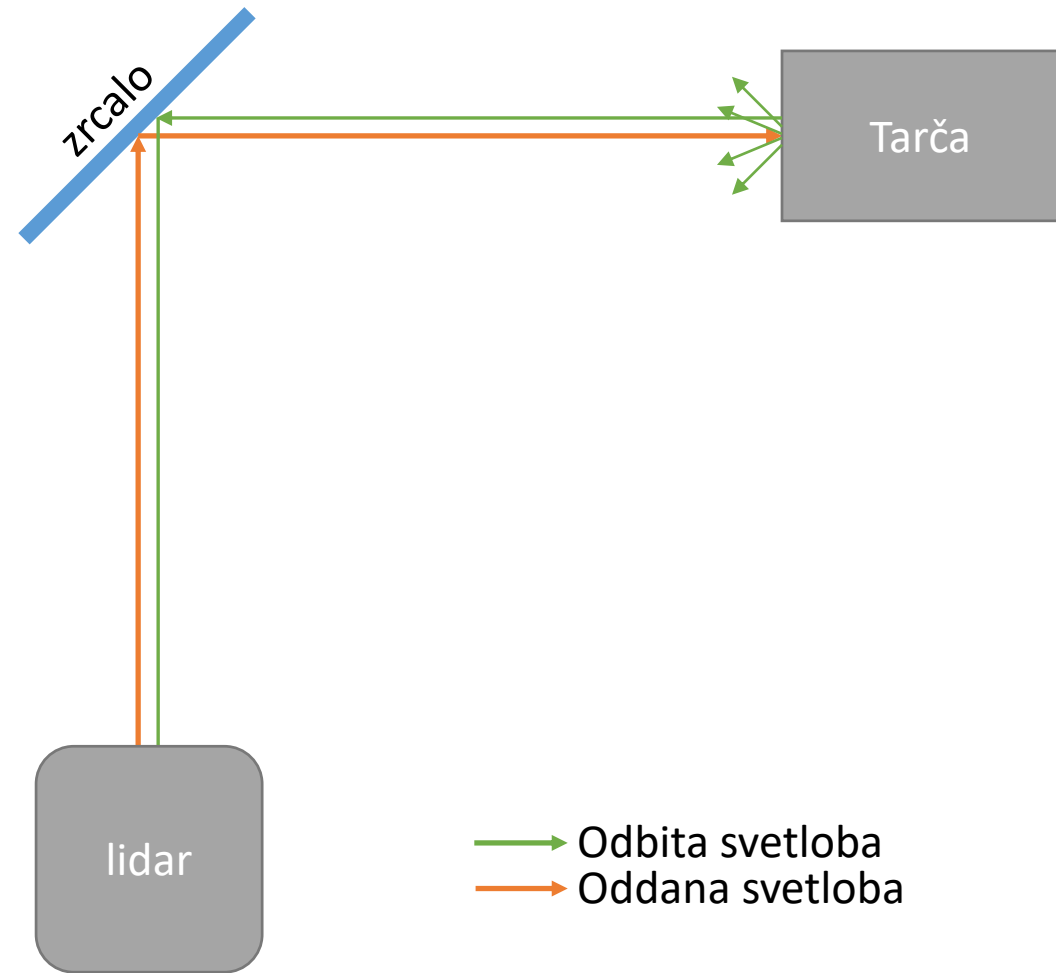
## Raziskovalna vprašanja

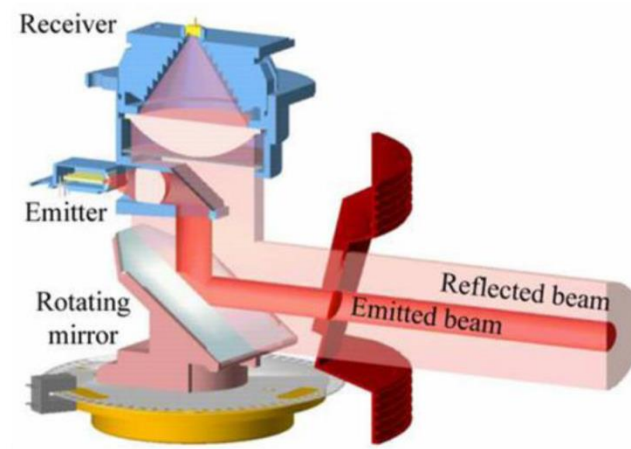
- Kako izdelati primeren lidarski sistem s premaknjenim vidnim poljem z uporabo stacionarnih optičnih elementov.
- Kako na delovanje sistema vpliva uporaba več vidnih polj.
- Ali je mogoče med gibanjem robota z lidarsko svetlobno ovojnico v realnem času na uporaben način trenutne meritve lidarjev primerjati z vnaprej zajetimi referenčnimi vrednostmi in s tem zaznavati spremembe geometrije okolice.

## Raziskovalna vprašanja

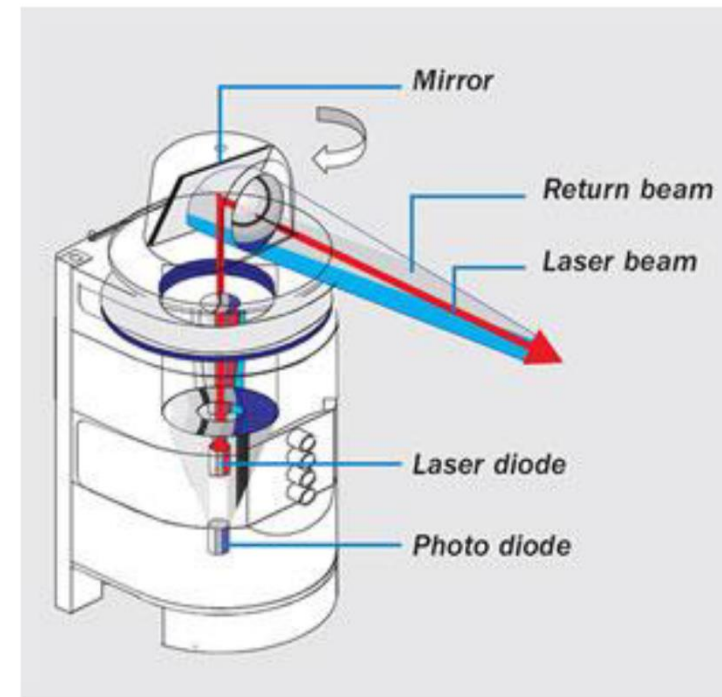
- Kako izdelati primeren lidarski sistem s premaknjenim vidnim poljem z uporabo stacionarnih optičnih elementov.
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# Preusmerjanje z zrcalom



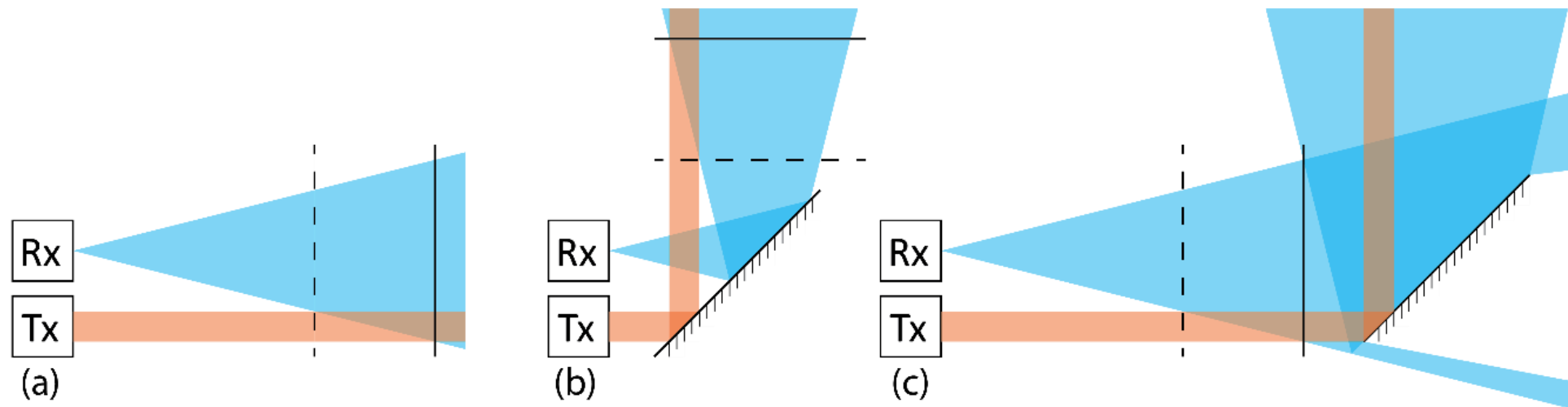


(a)



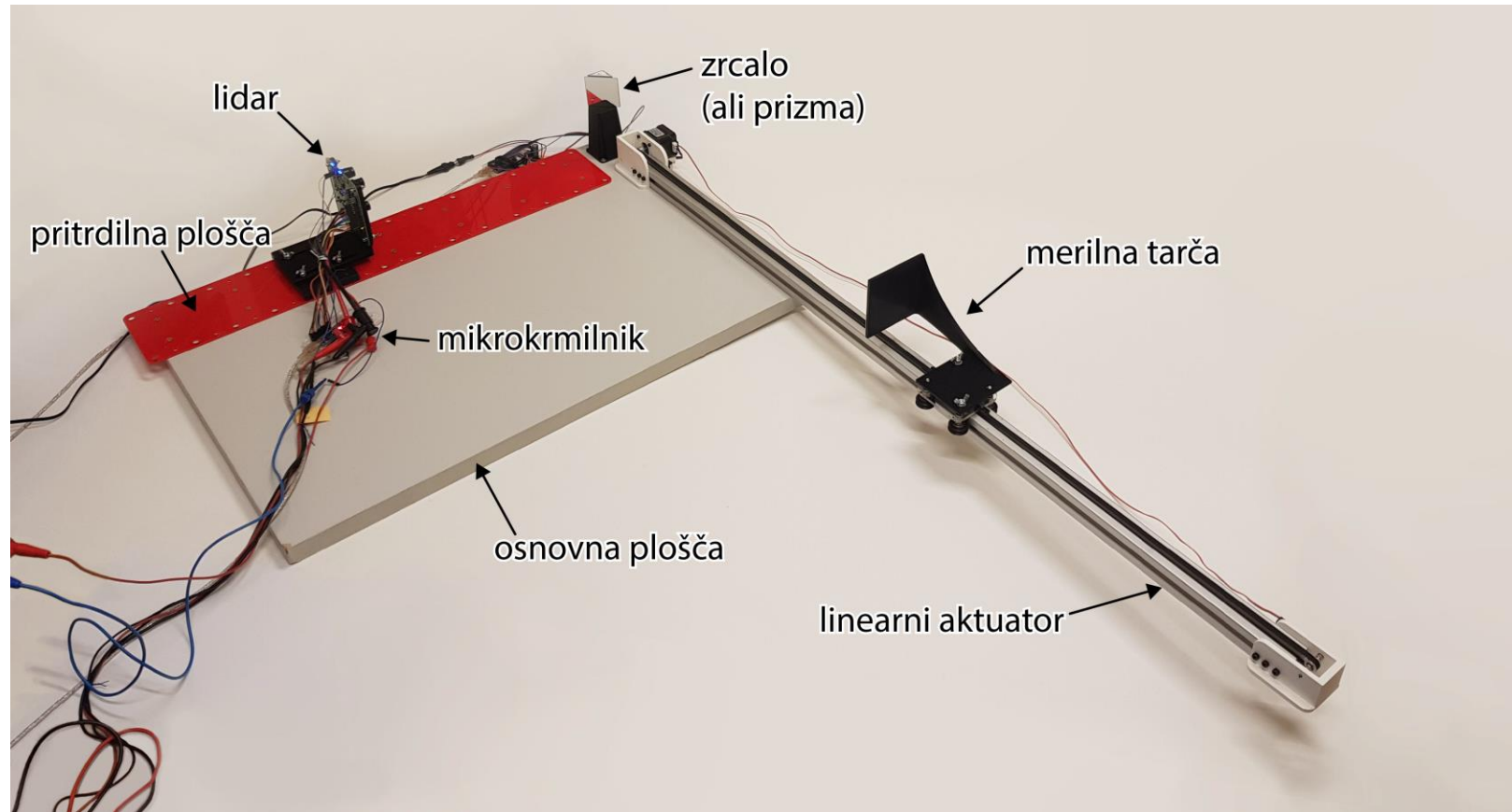
(b)

# Vpliv zrcala na lidarjevo vidno polje



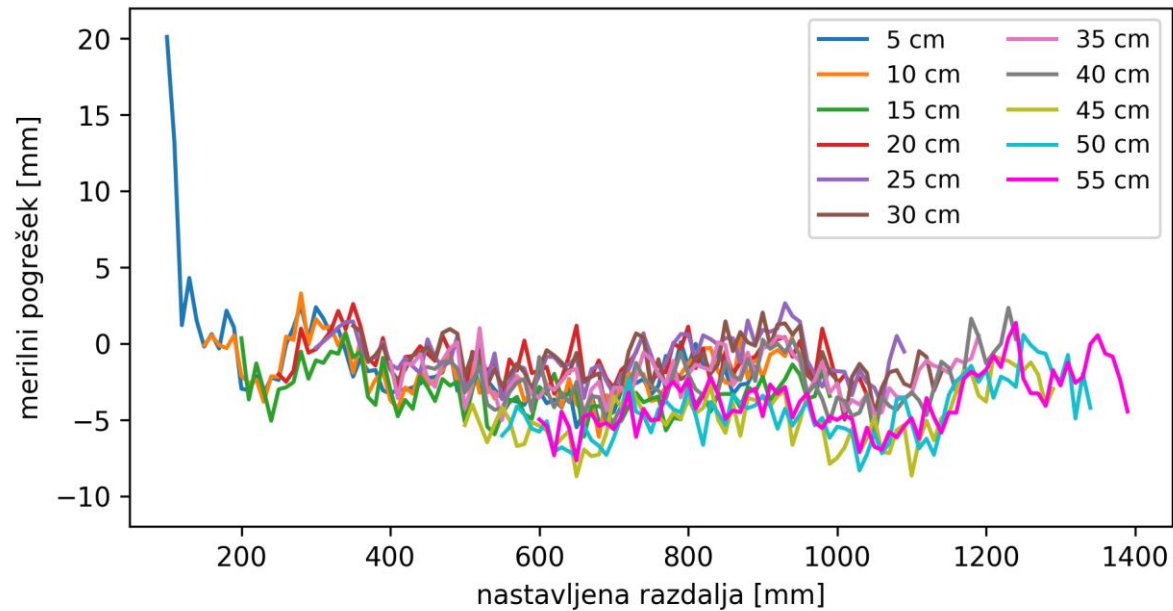


# Merilna postavititev

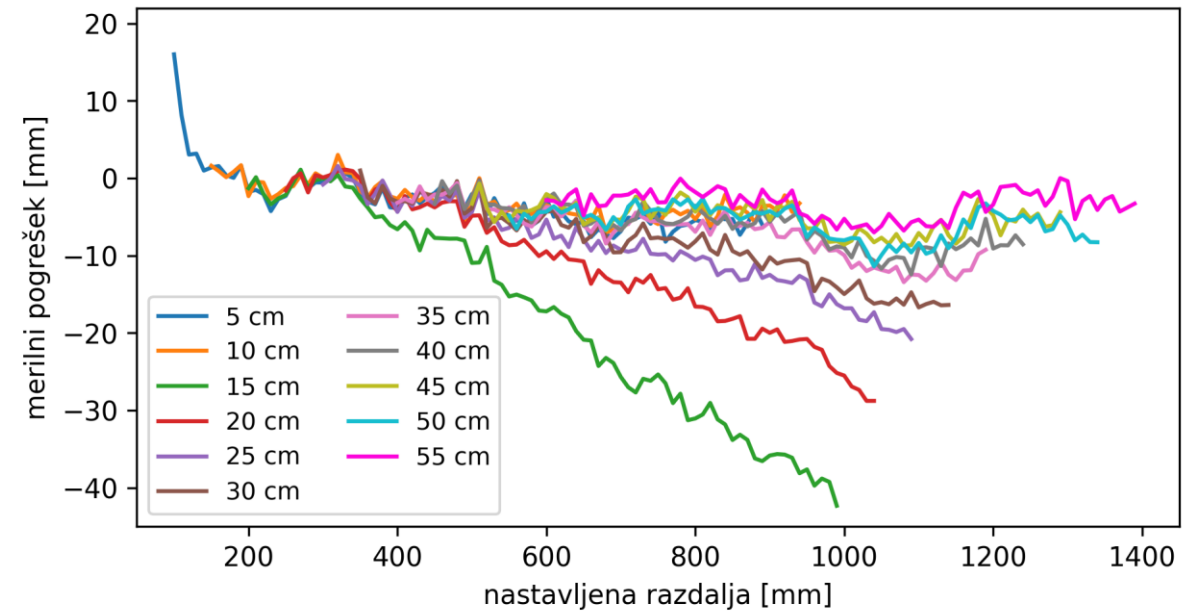


# Meritev prek čistega zrcala

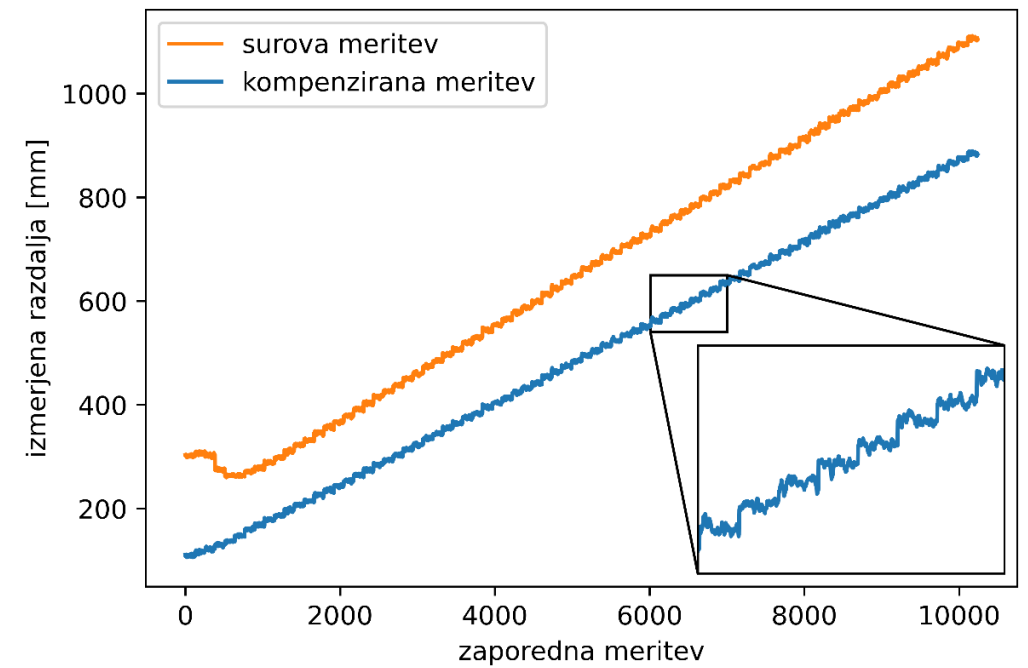
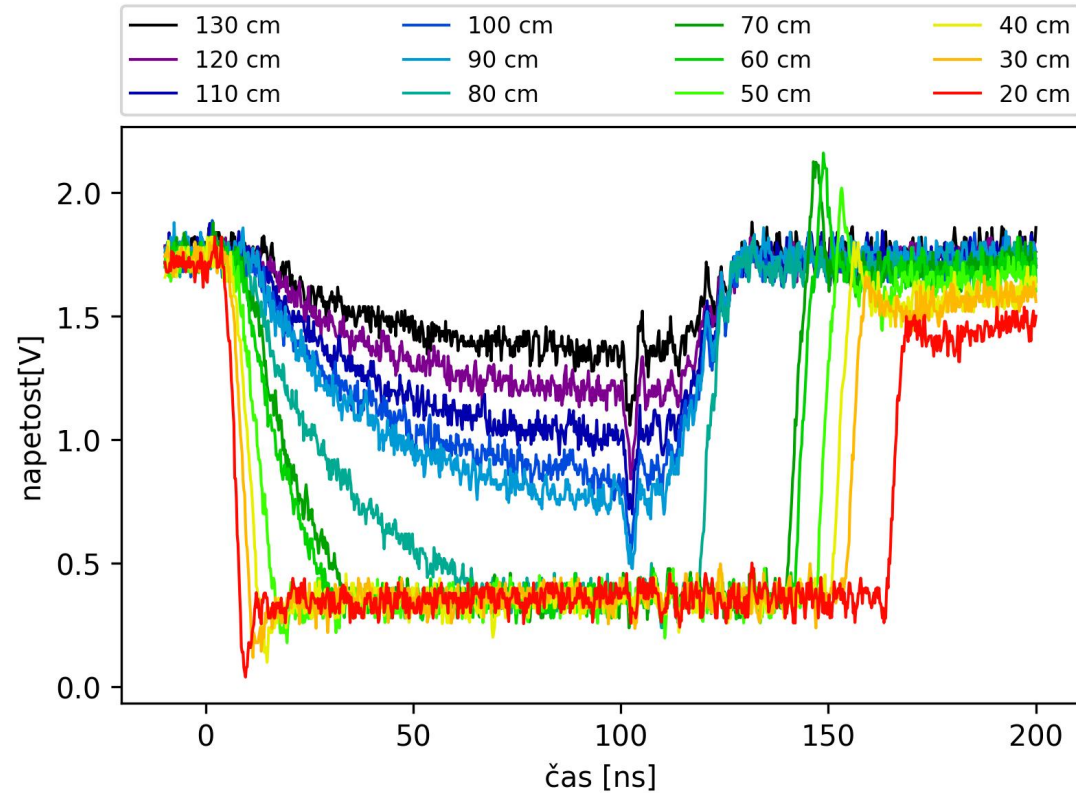
## čisto zrcalo



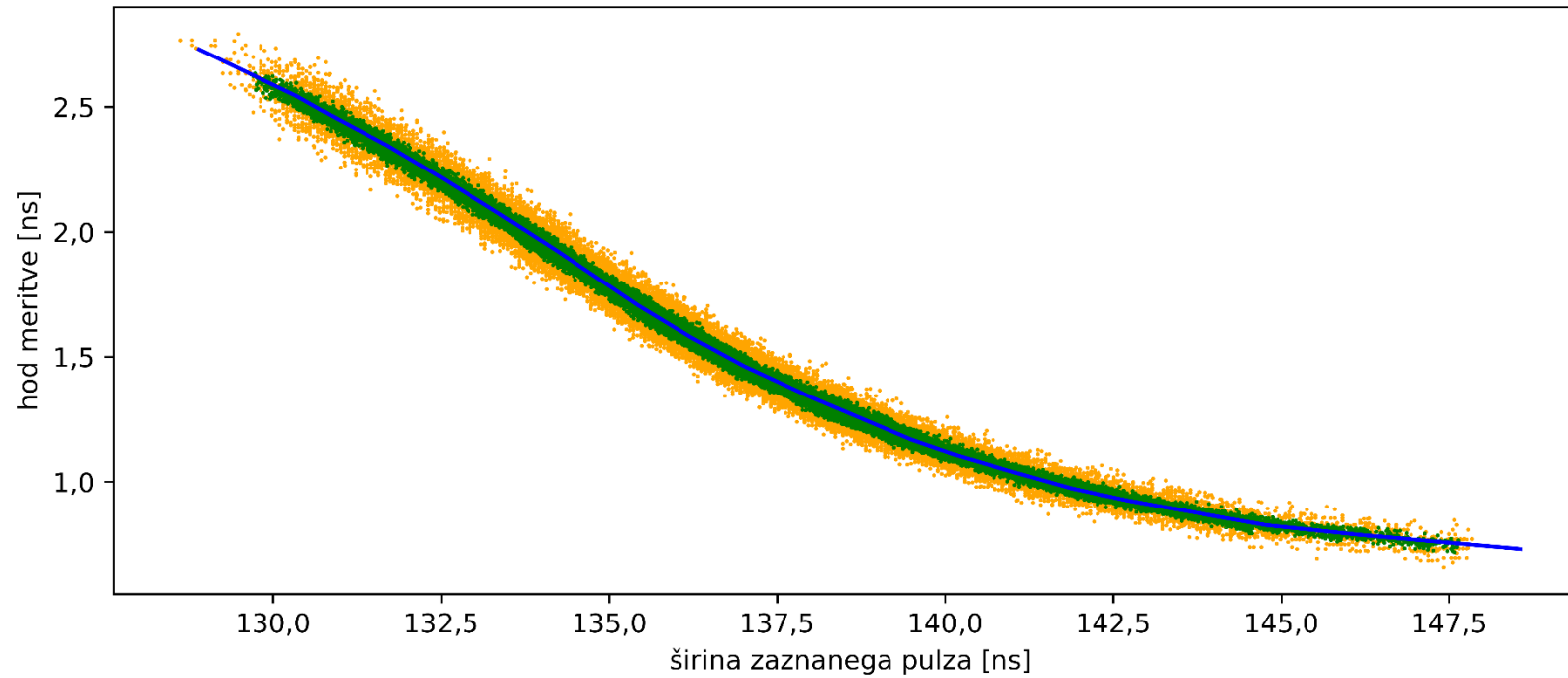
## zprašeno zrcalo



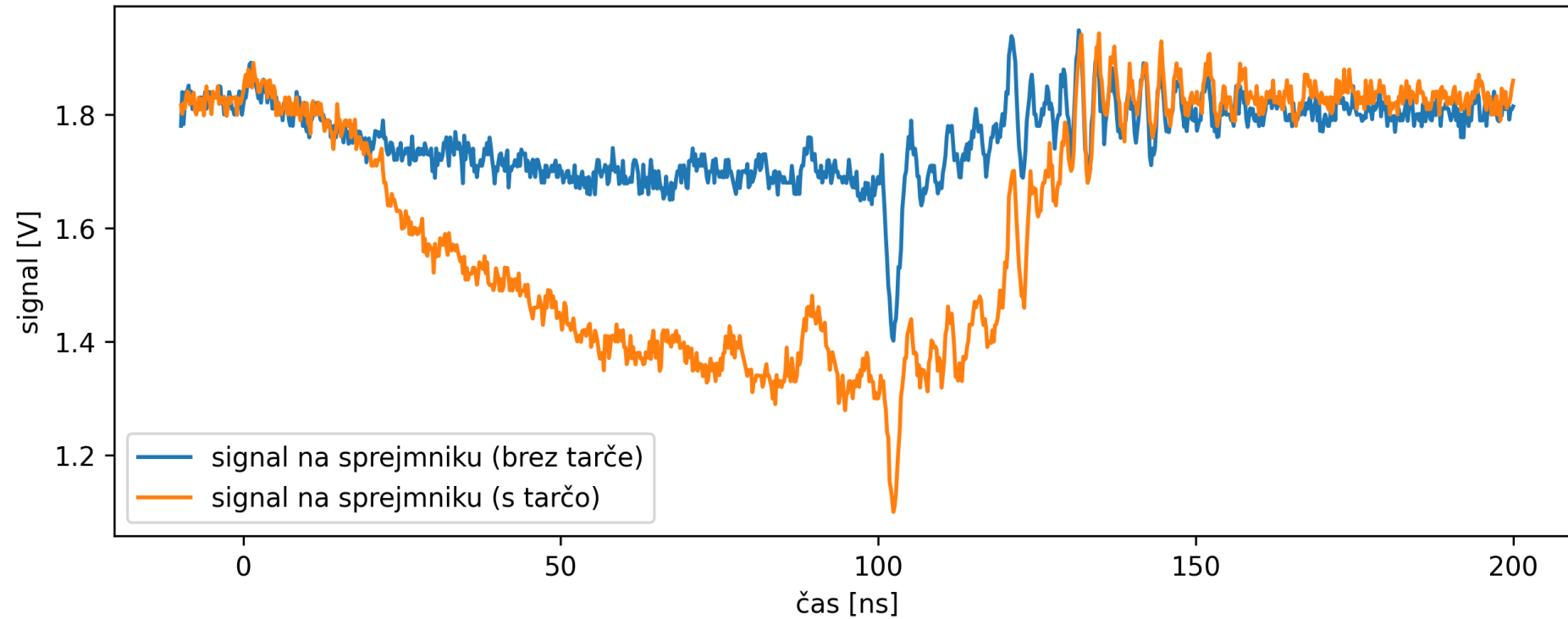
# Hod meritve



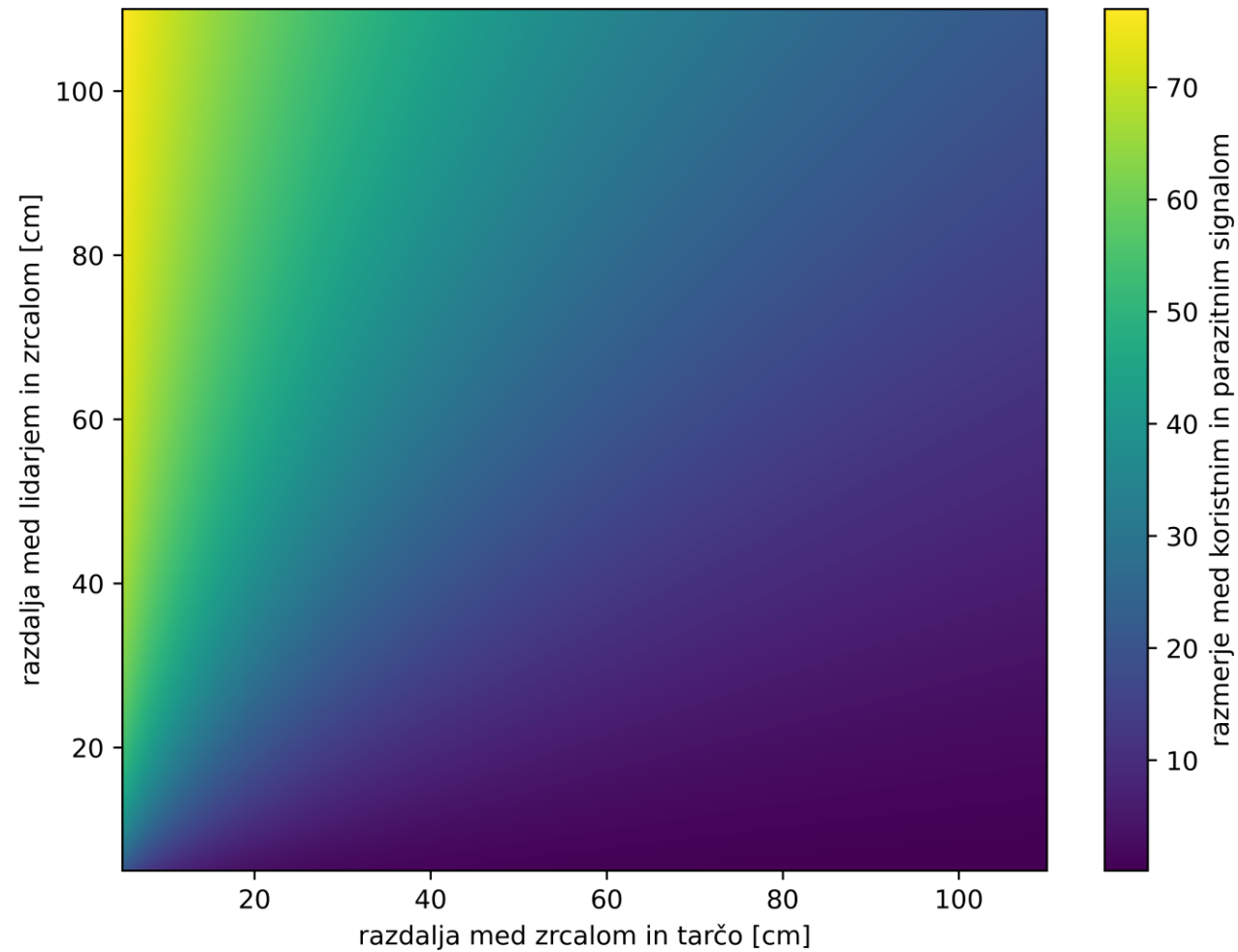
# Kompenzacija hoda meritve



# Sprejemni signal pri zaprašenem zrcalu



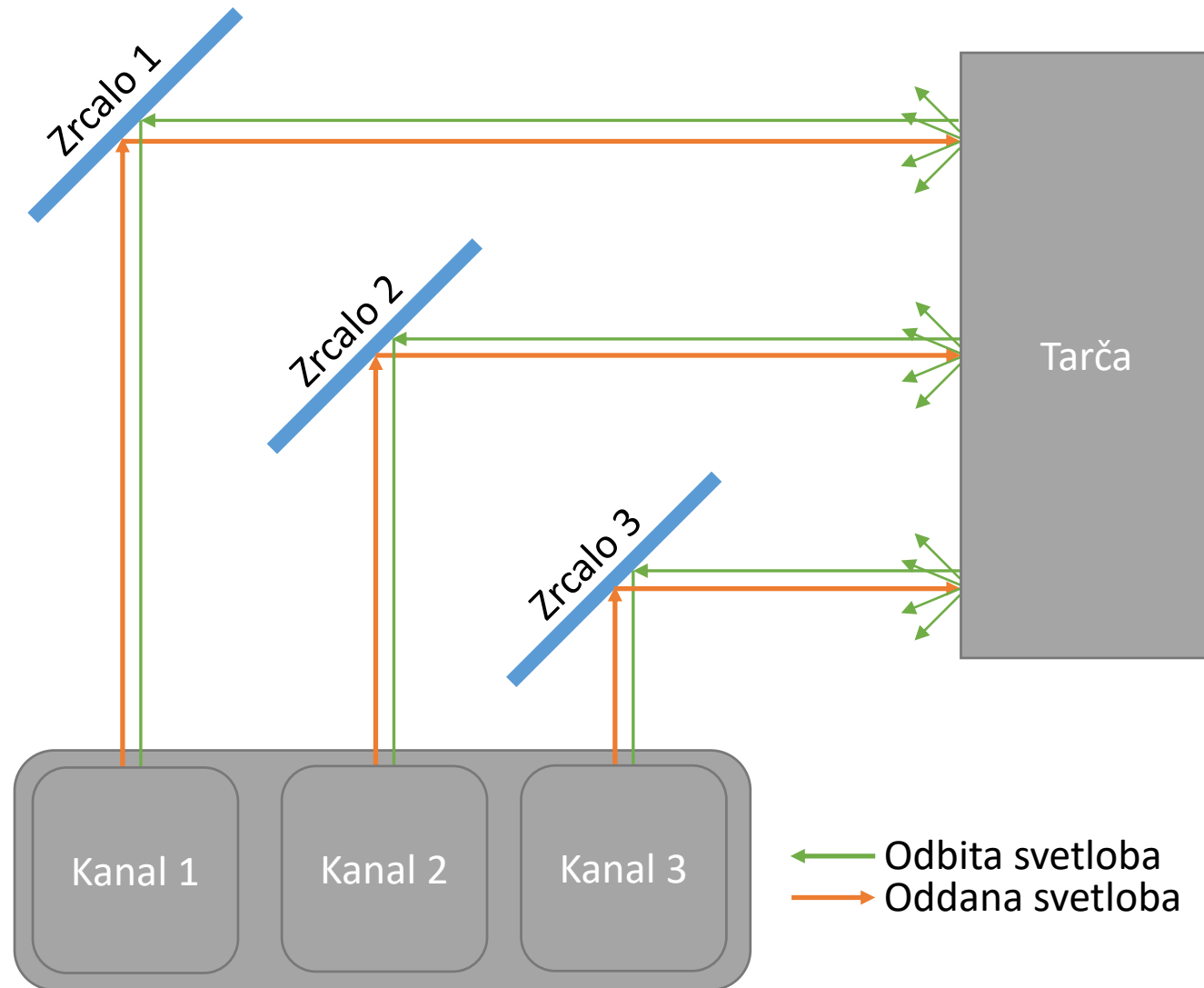
# Razmerje med koristnim in parazitnim signalom



## Raziskovalna vprašanja

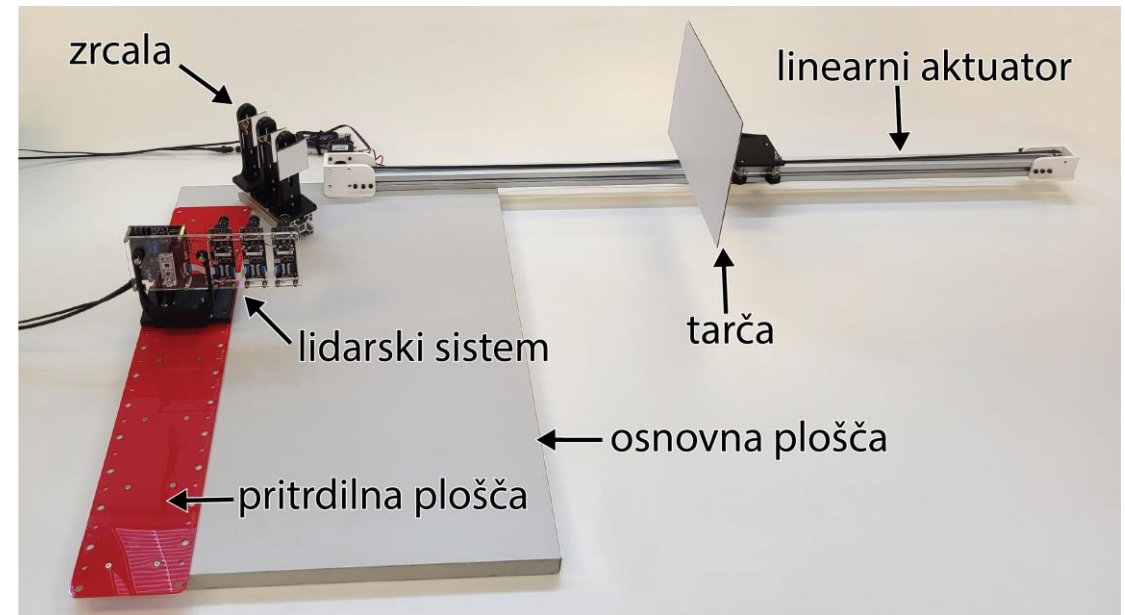
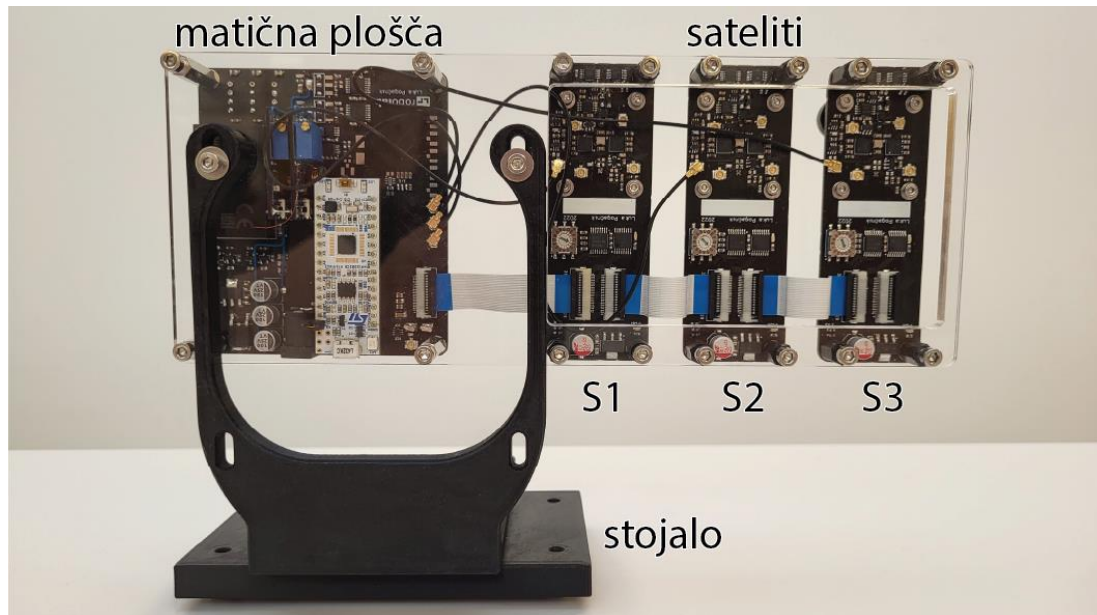
- Kako izdelati primeren lidarski sistem s premaknjenim vidnim poljem z uporabo stacionarnih optičnih elementov.
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# Sočasno preusmerjanje svetlobe iz več kanalov

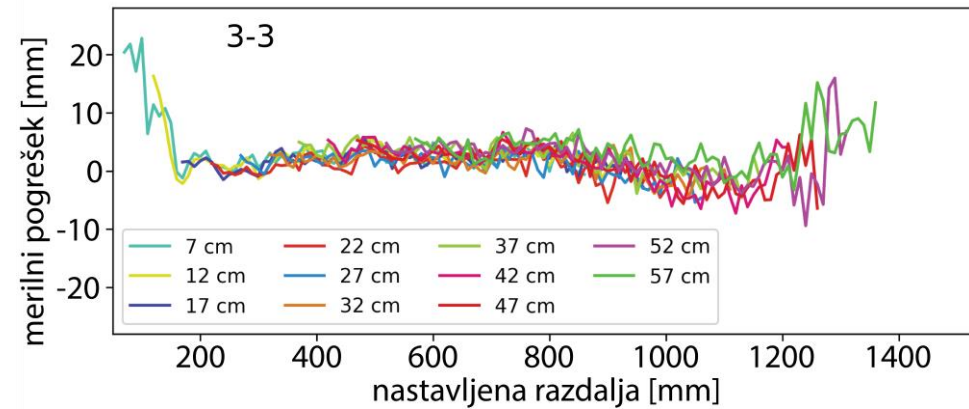
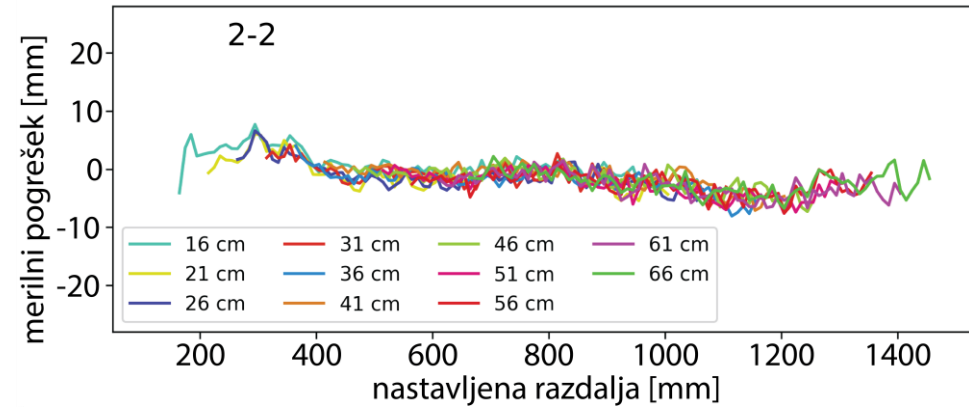
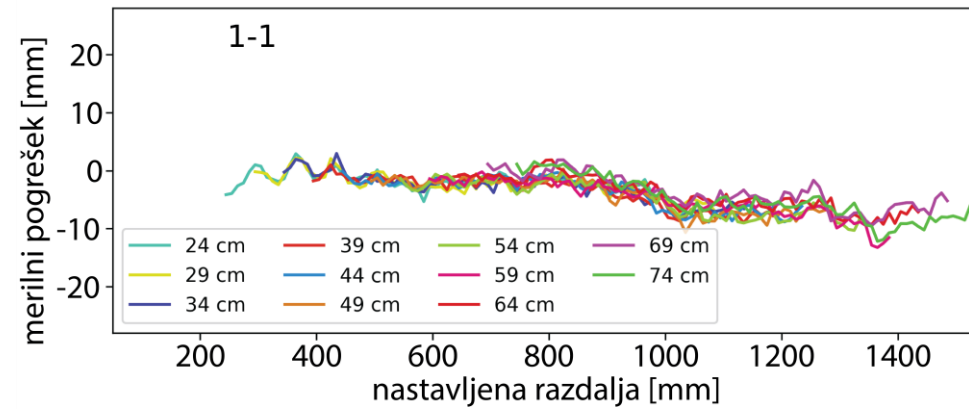




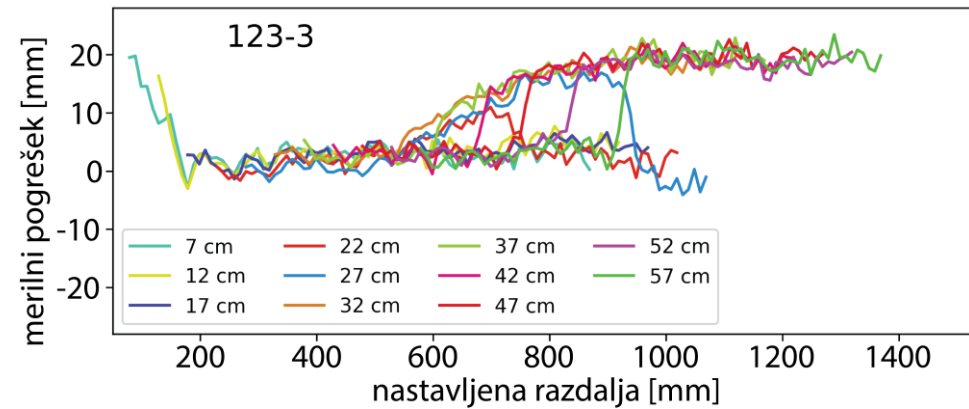
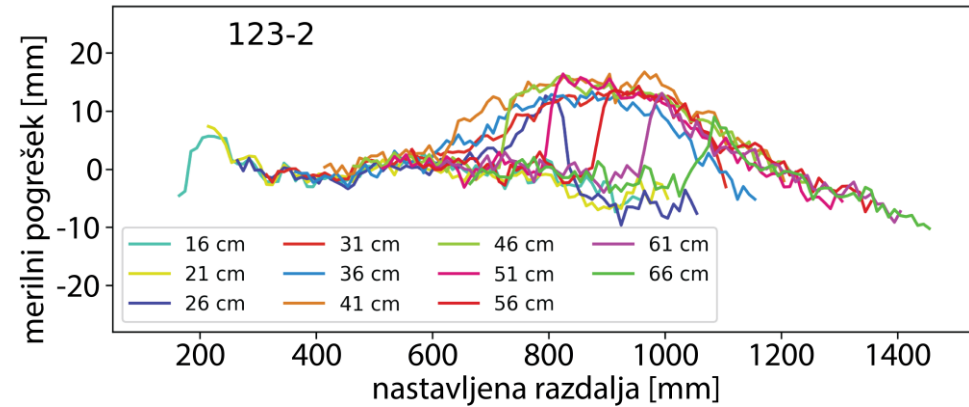
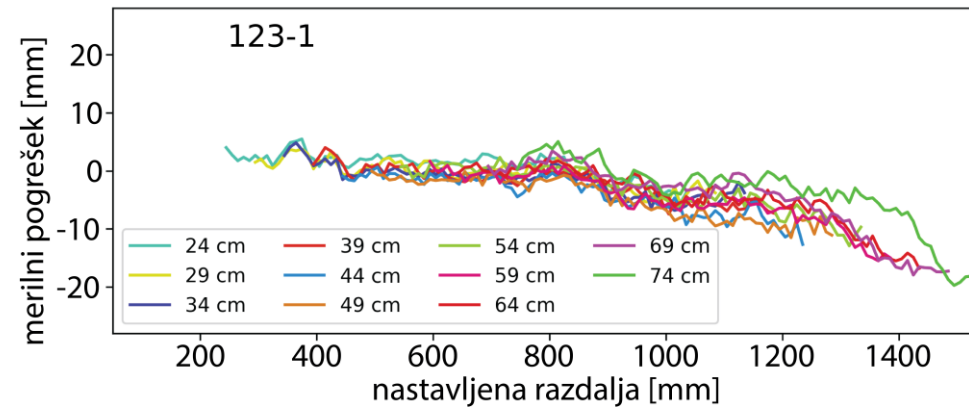
# Merilna postavititev



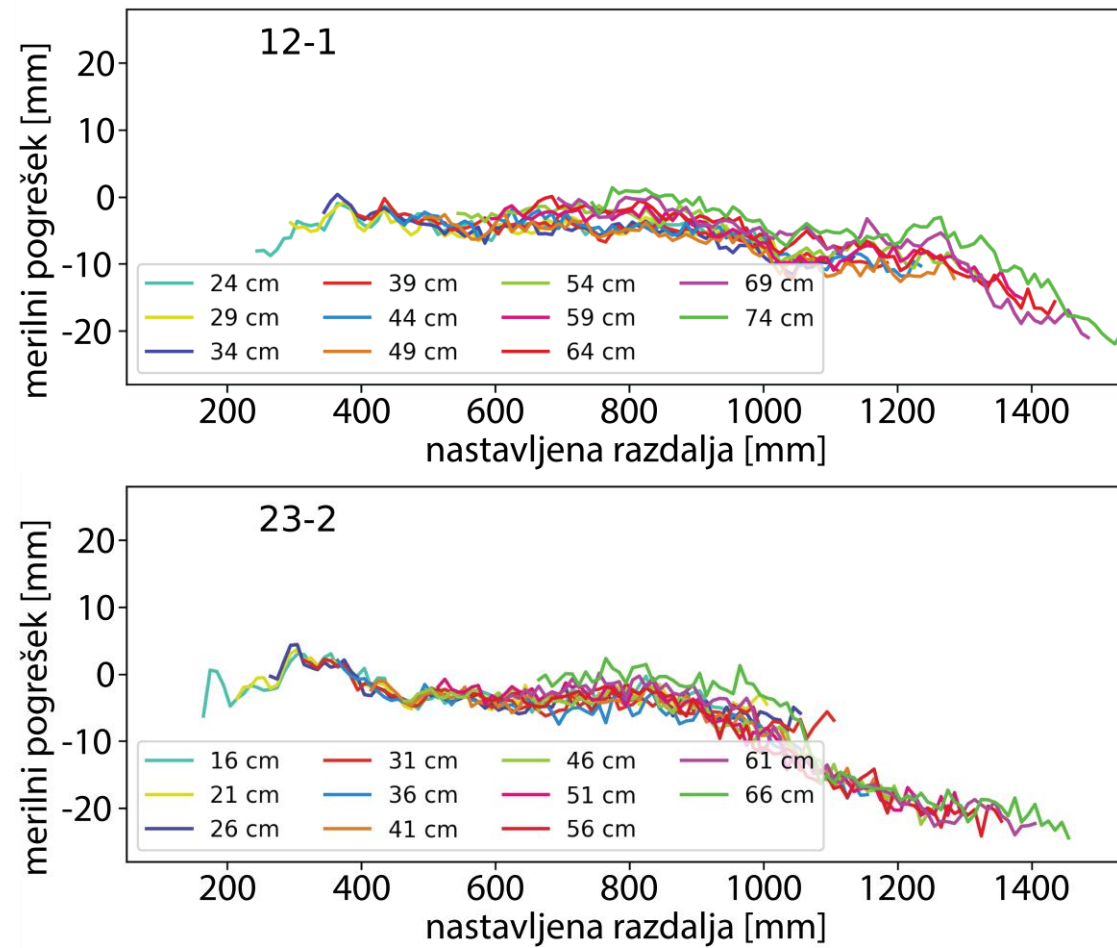
# En kanal hkrati



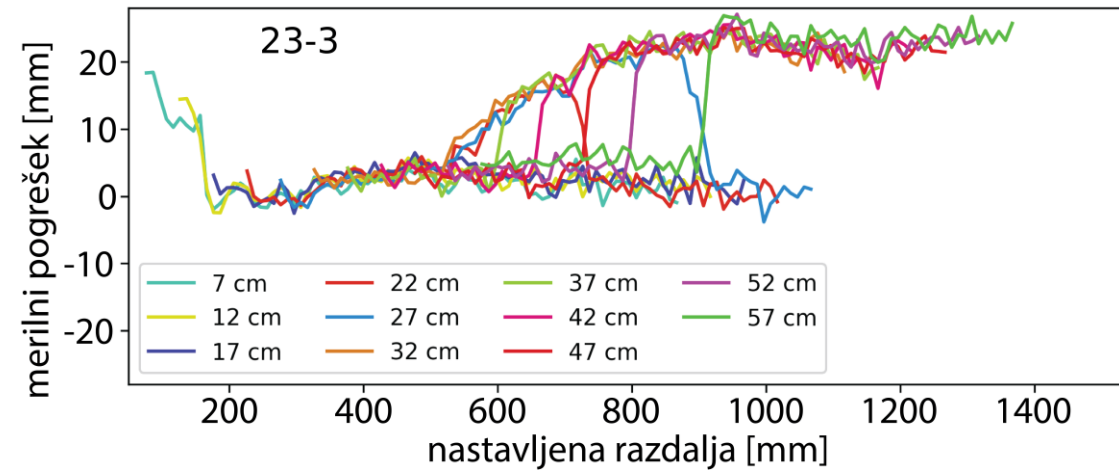
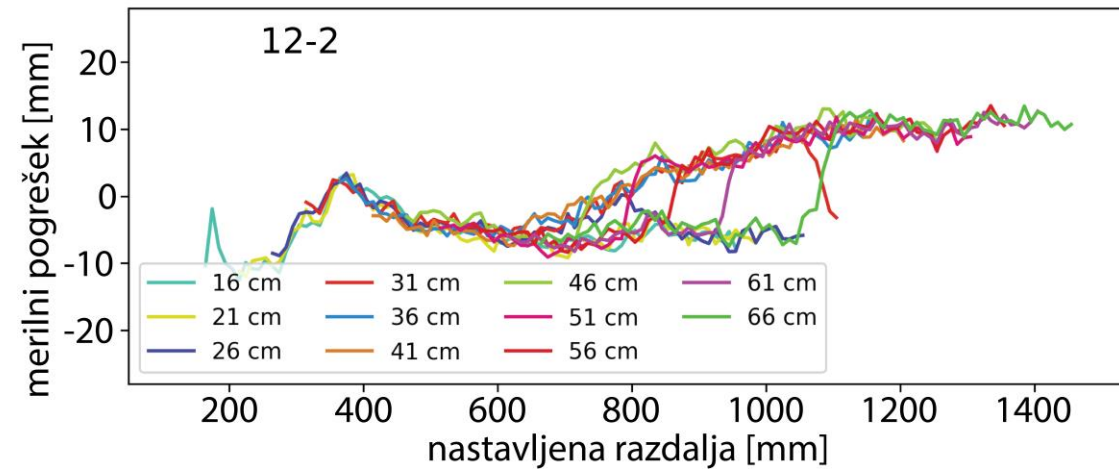
# Vsi kanali hkrati



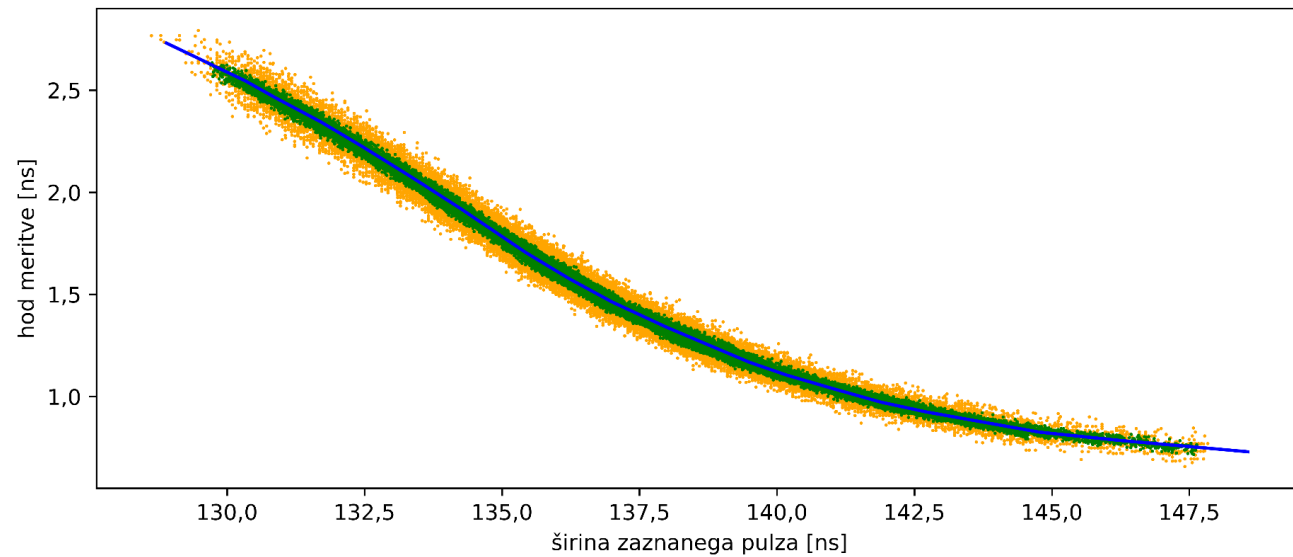
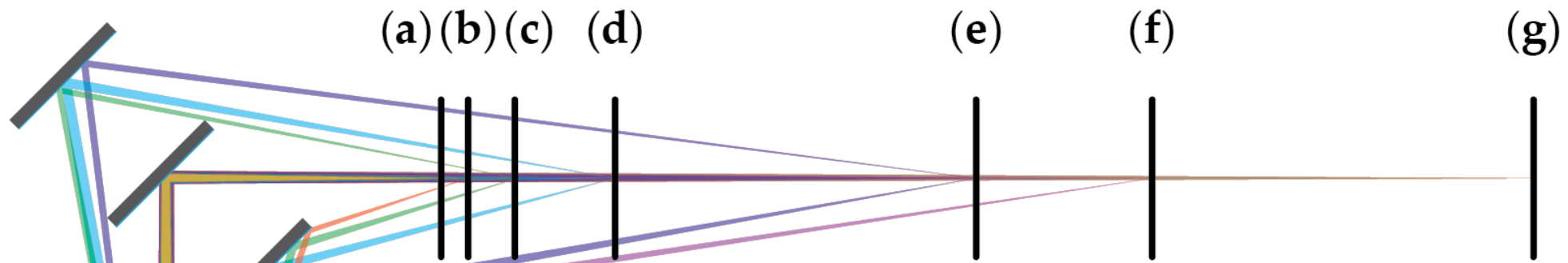
# Preusmeritev na dveh sosednjih kanalih



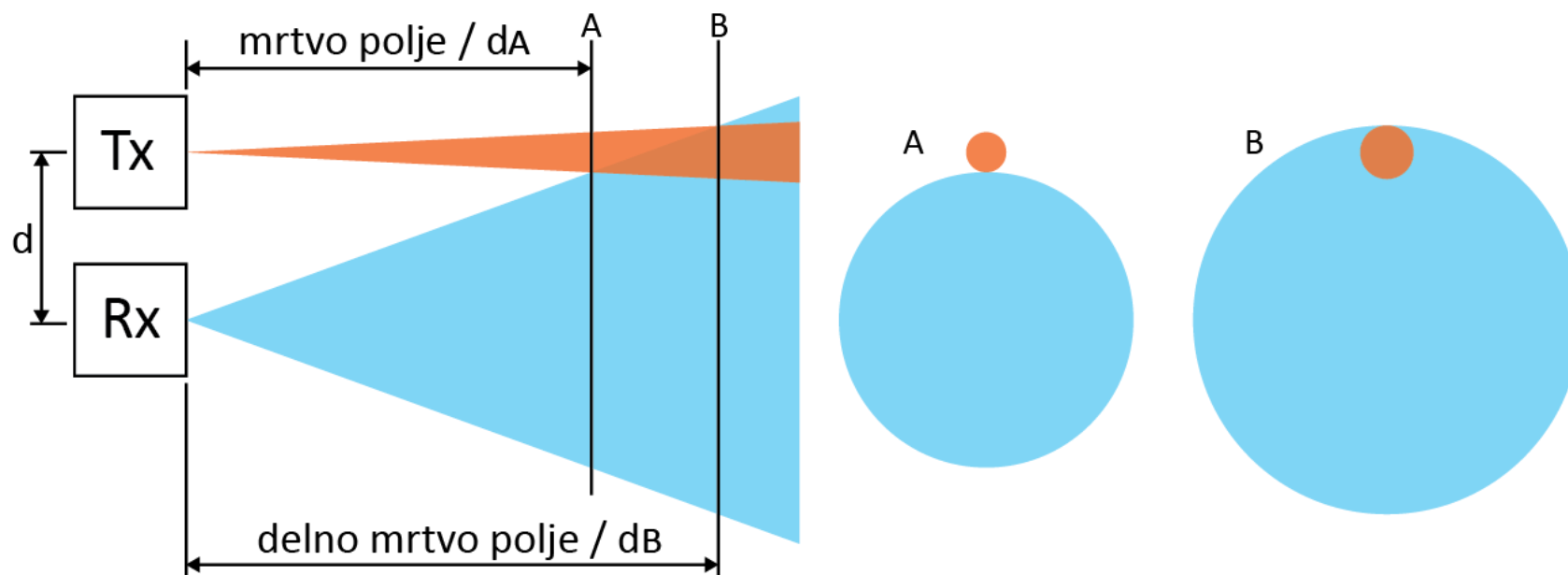
# Zrcalo na levem sosednjem kanalu



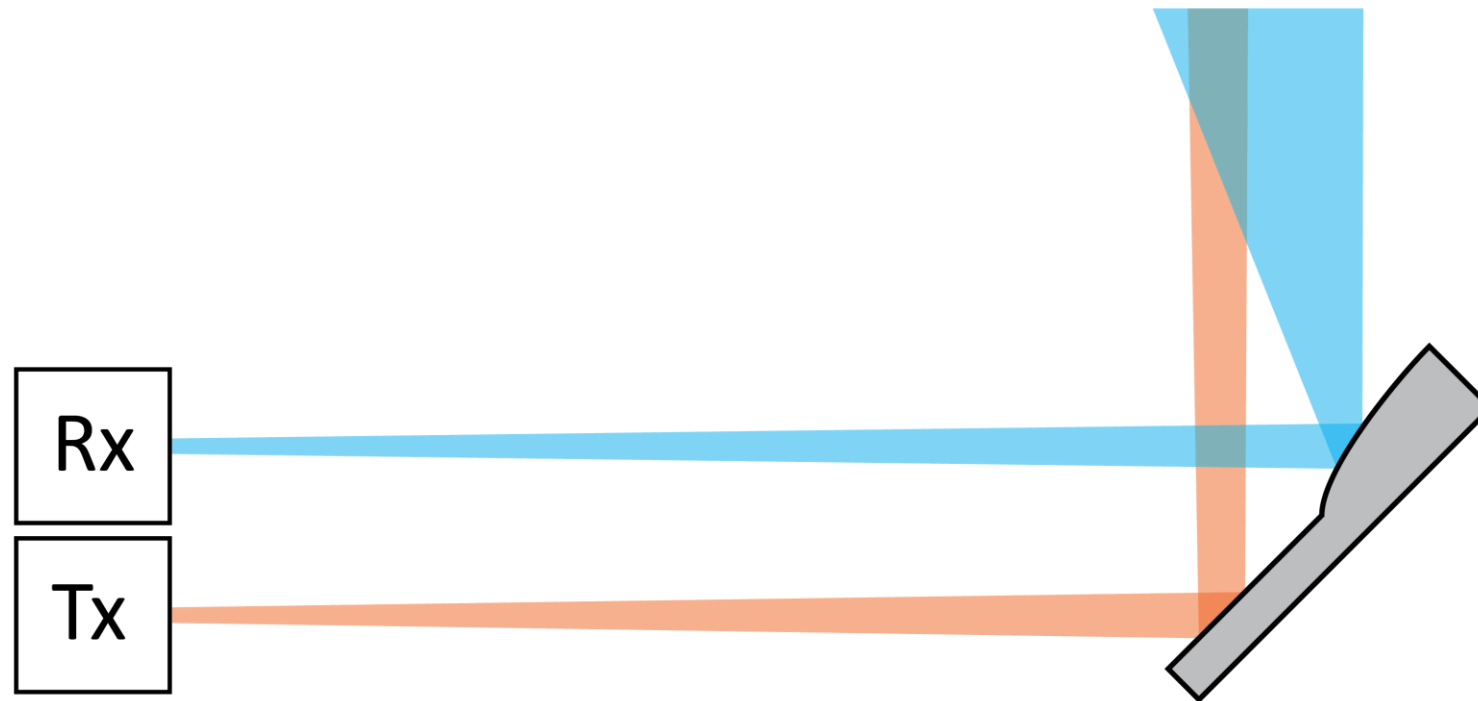
# Simulacija svetlobnih poti



# Lidarjevo vidno polje

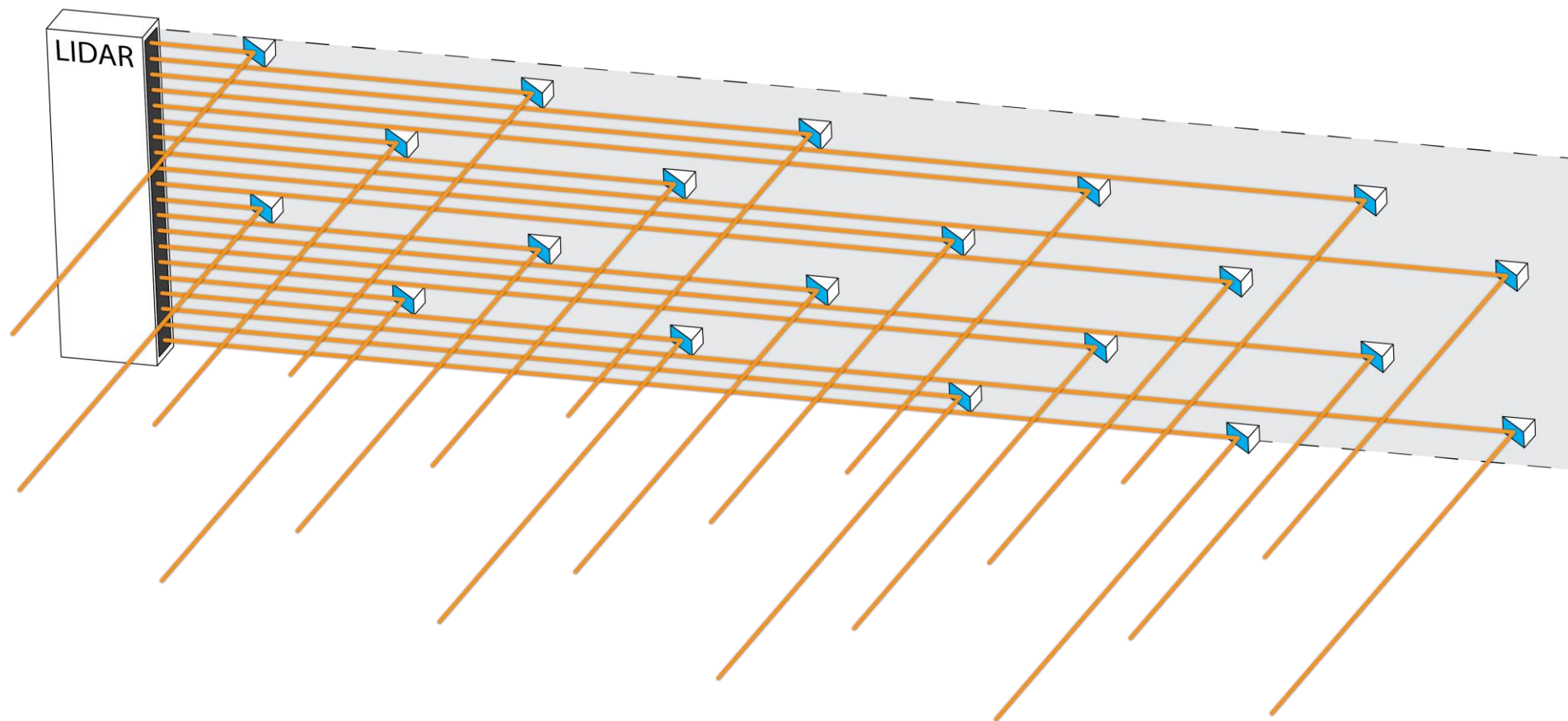


# Uporaba neplanarnega zrcala





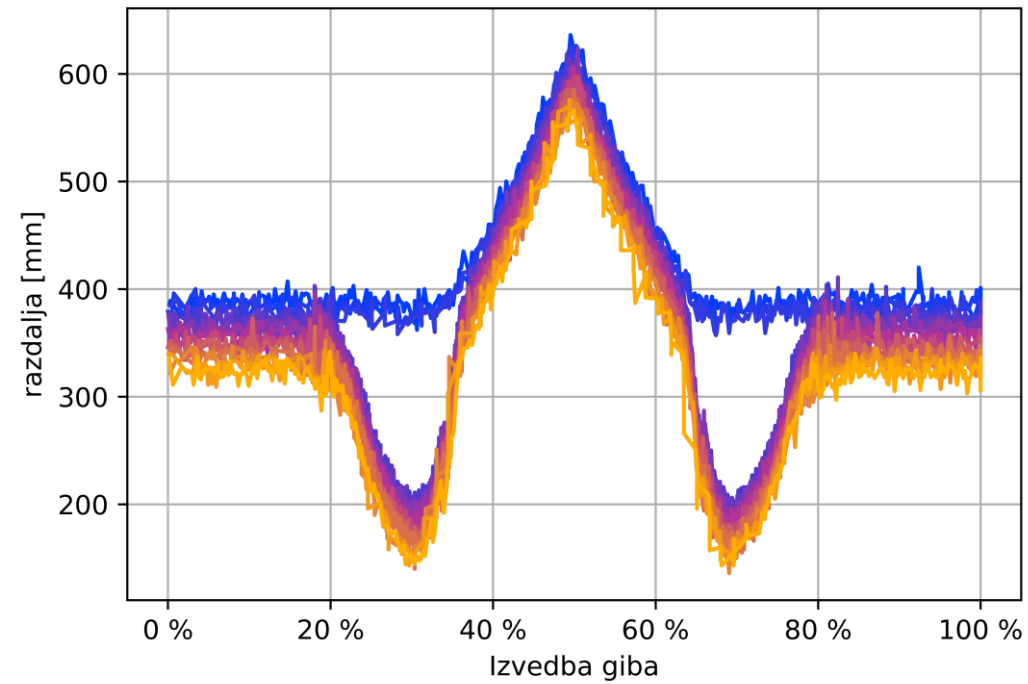
# Primer možne uporabe predlaganega sistema



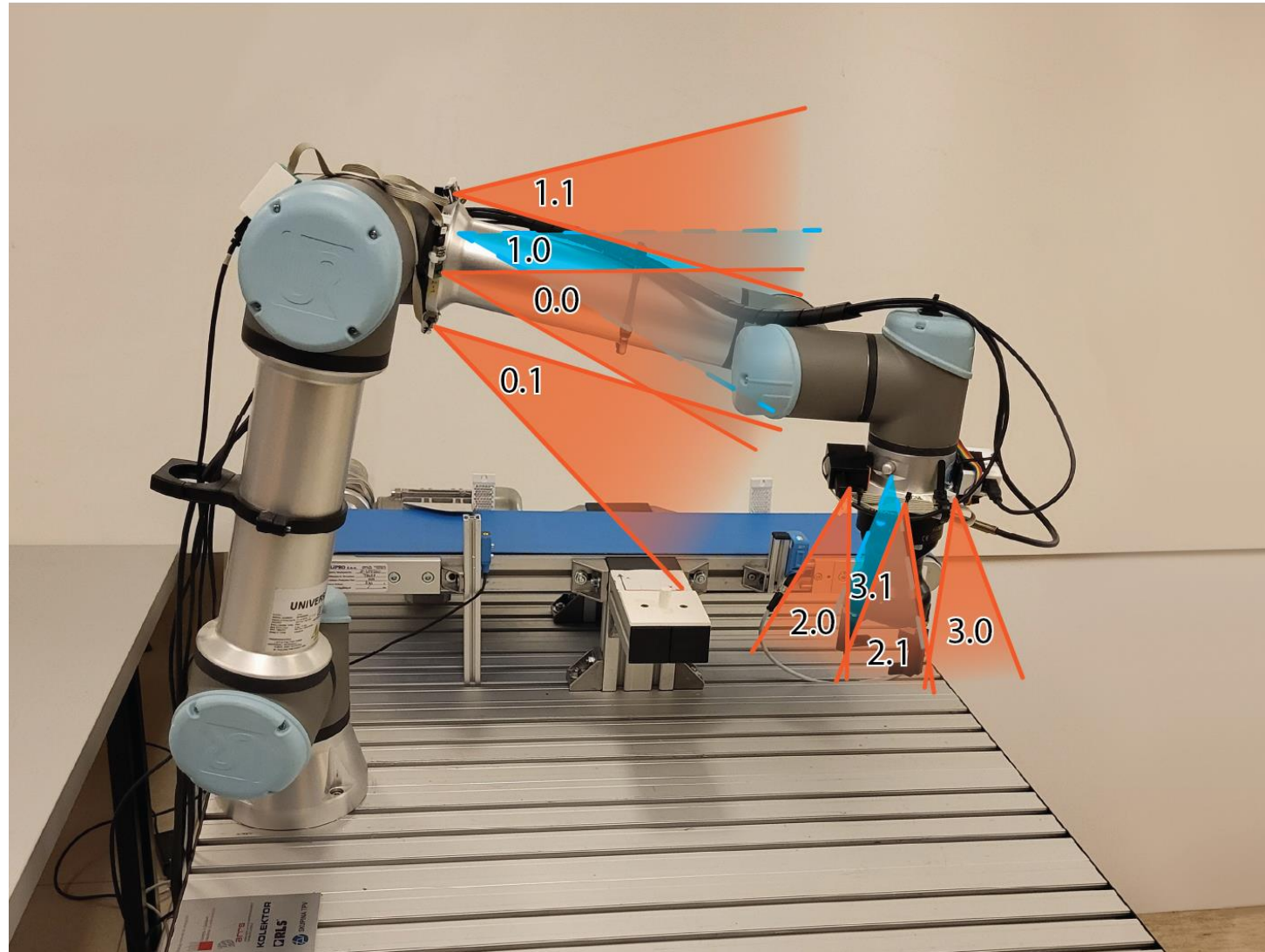
## Raziskovalna vprašanja

- Kako izdelati primeren lidarski sistem s premaknjenim vidnim poljem z uporabo stacionarnih optičnih elementov.
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- Ali je mogoče med gibanjem robota z lidarsko svetlobno ovojnico v realnem času na uporaben način trenutne meritve lidarjev primerjati z vnaprej zajetimi referenčnimi vrednostmi in s tem zaznavati spremembe geometrije okolice.

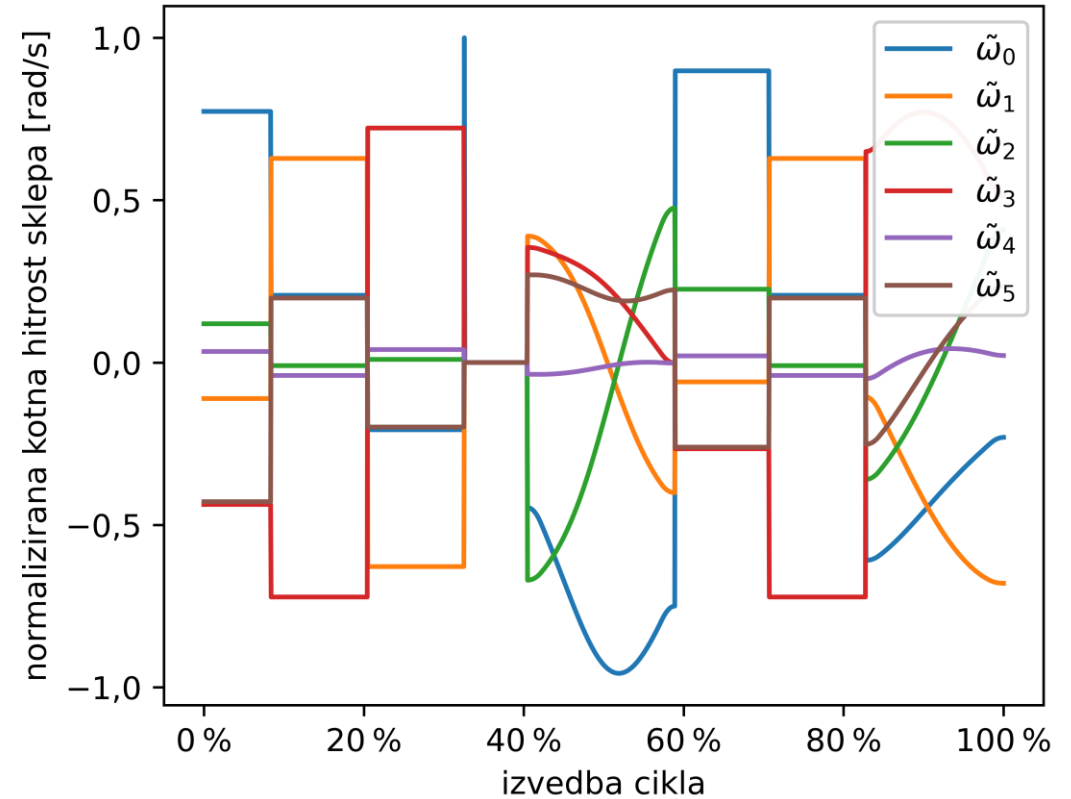
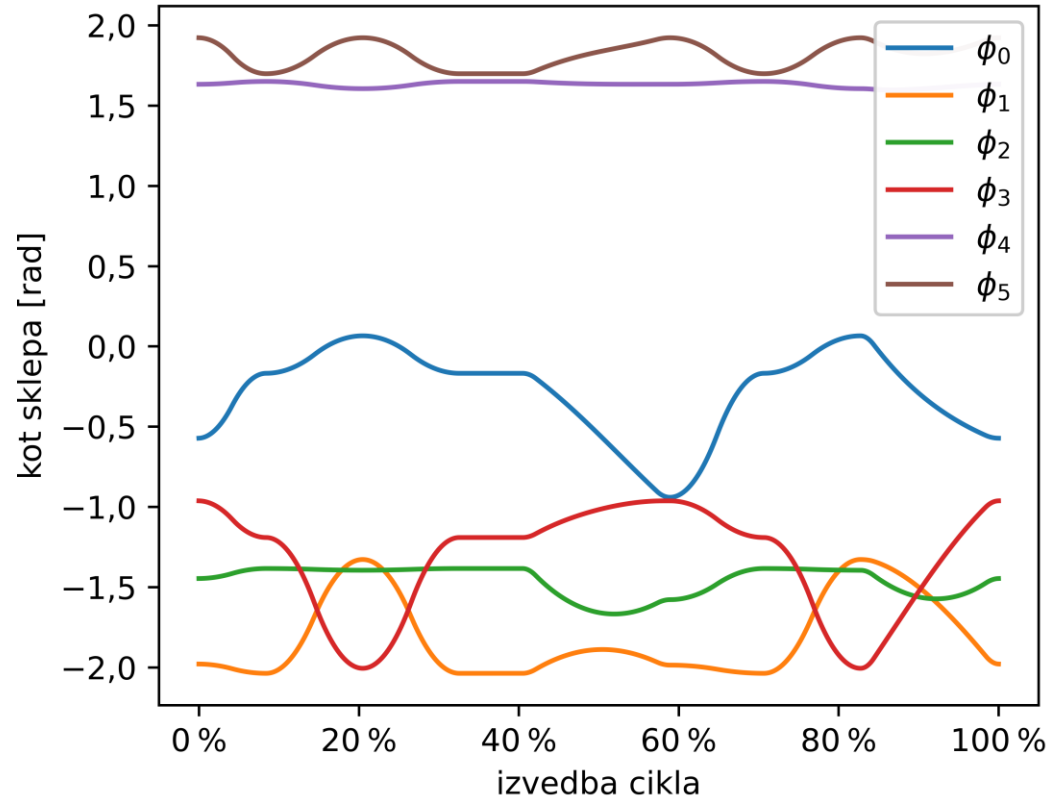
# Razdalje in referenca tekem preprostega giba



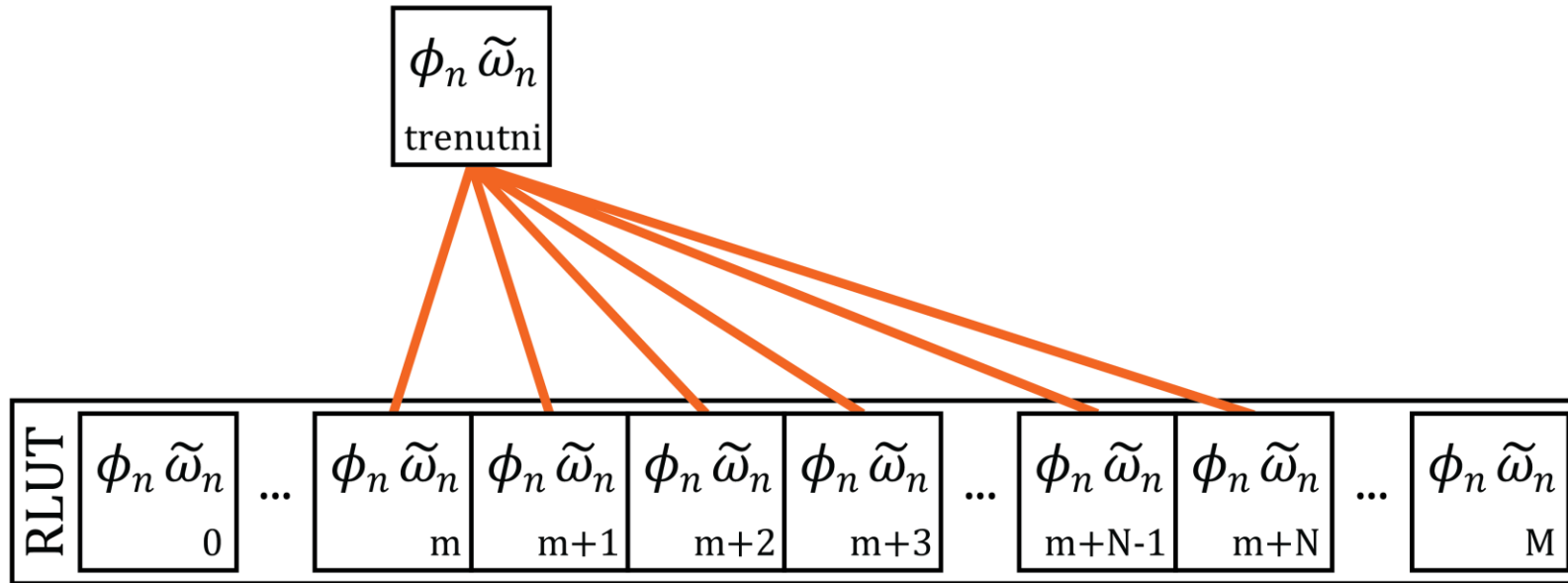
# Nadzor iz površine robota



# Koti in normirane hitrosti robotovih sklepov

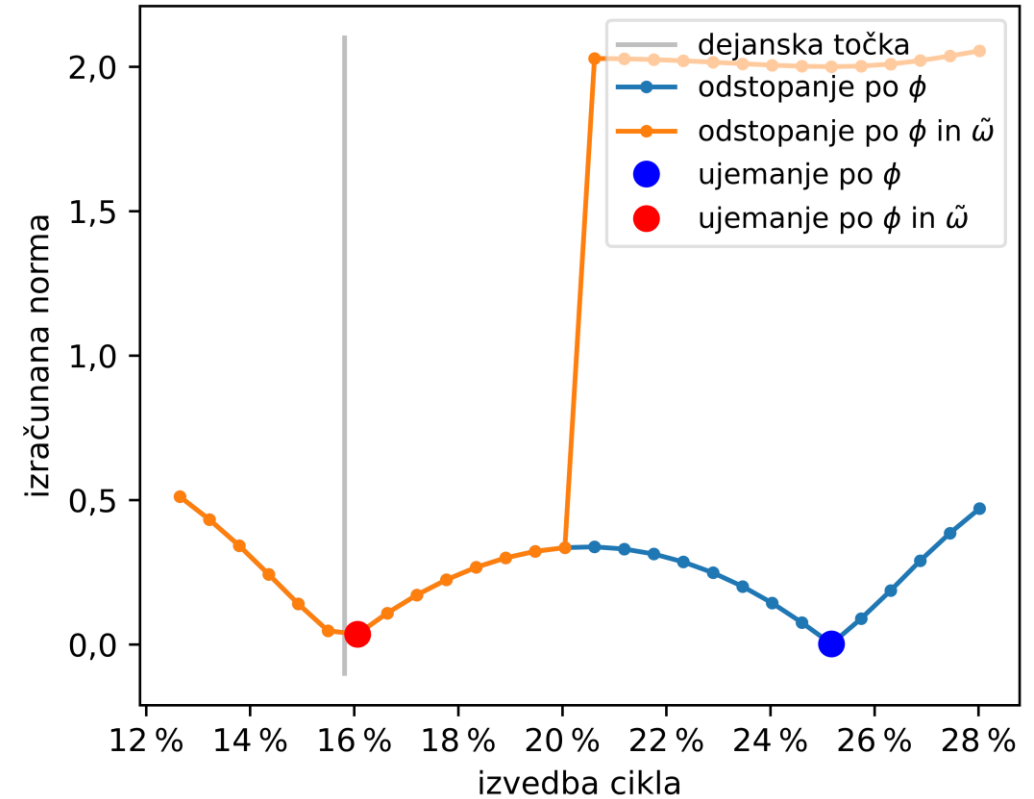
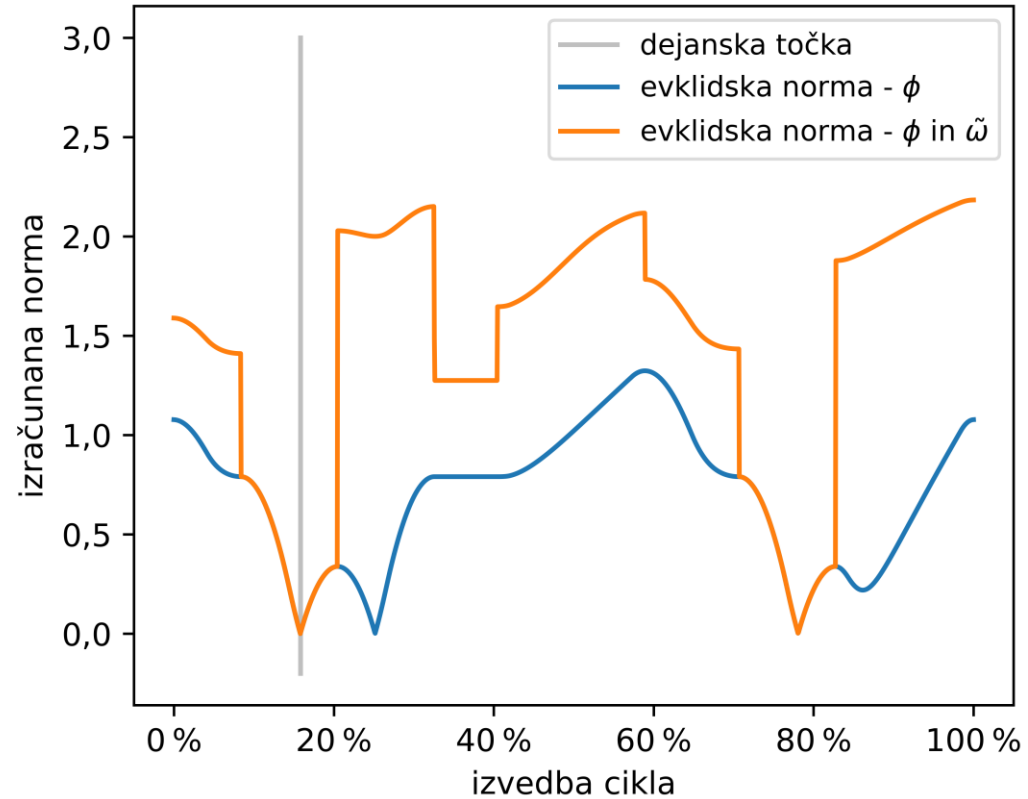


# Določanje ujemanja z referenčno vrednostjo

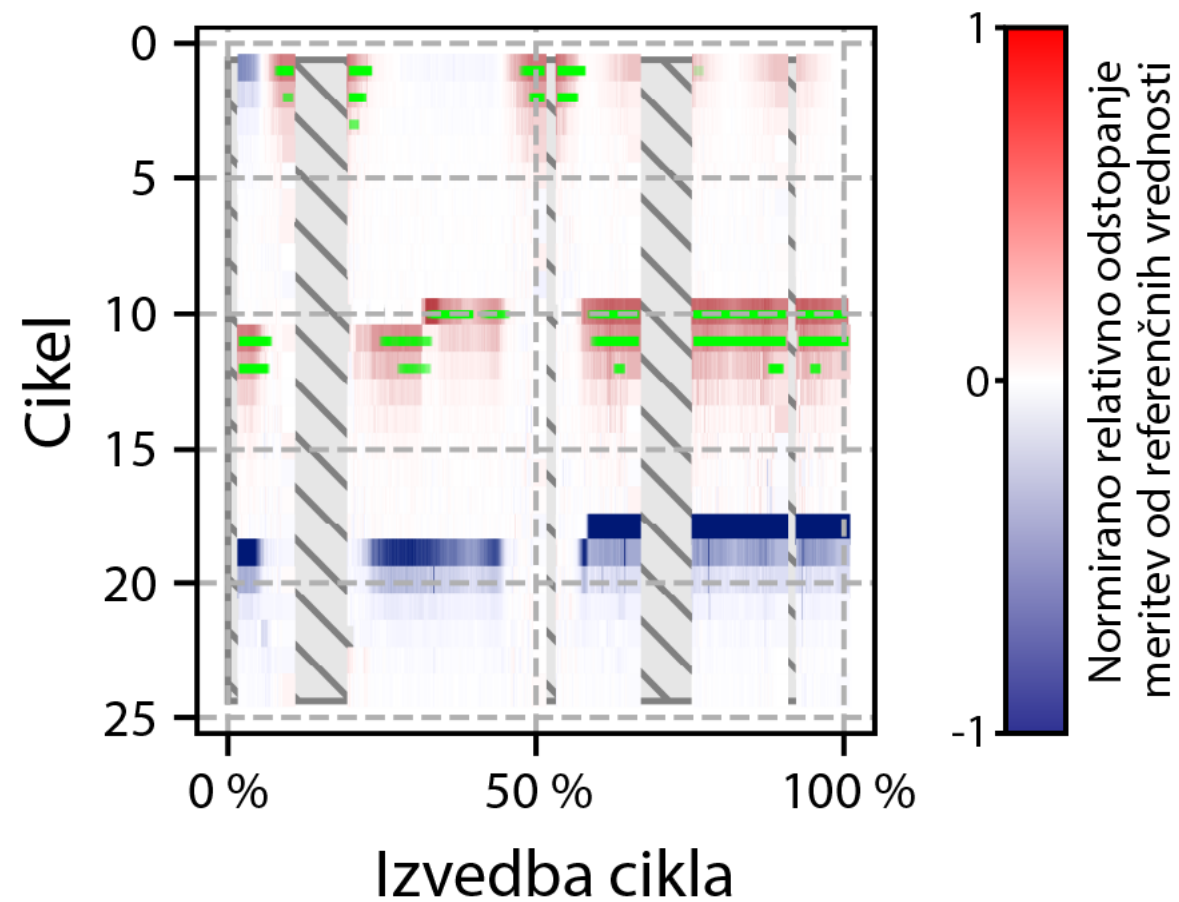
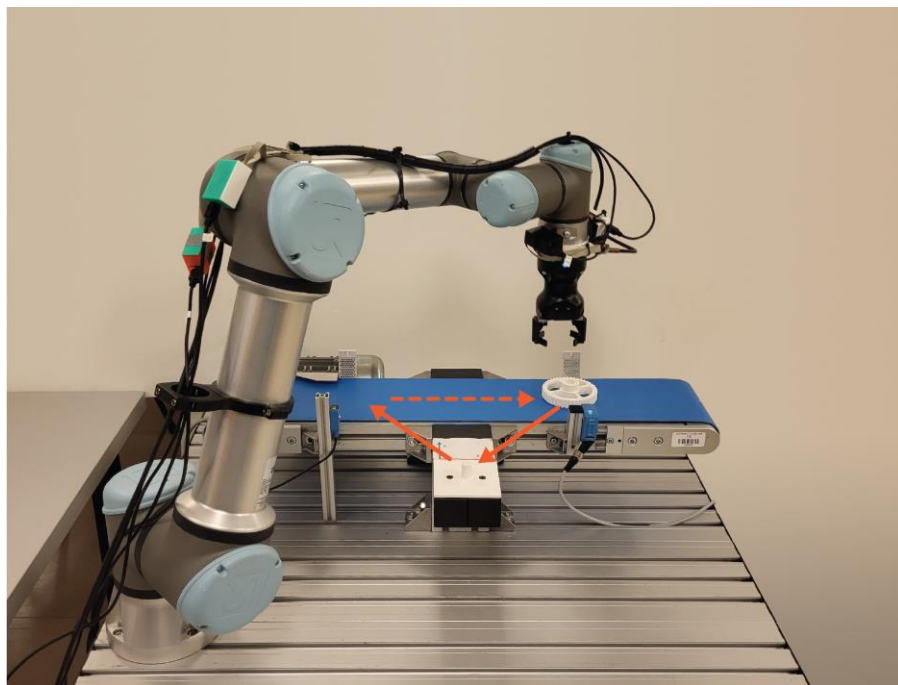


$$\text{indeks} = \operatorname{argmin}_{i \in [m, m+N]} \left( \sqrt{\sum_{n=0}^6 \left( (\phi_{n,i} - \phi_{n,\text{trenutni}})^2 + (\tilde{\omega}_{n,i} - \tilde{\omega}_{n,\text{trenutni}})^2 \right)} \right)$$

# Izračun ujemanja z referenčno vrednostjo

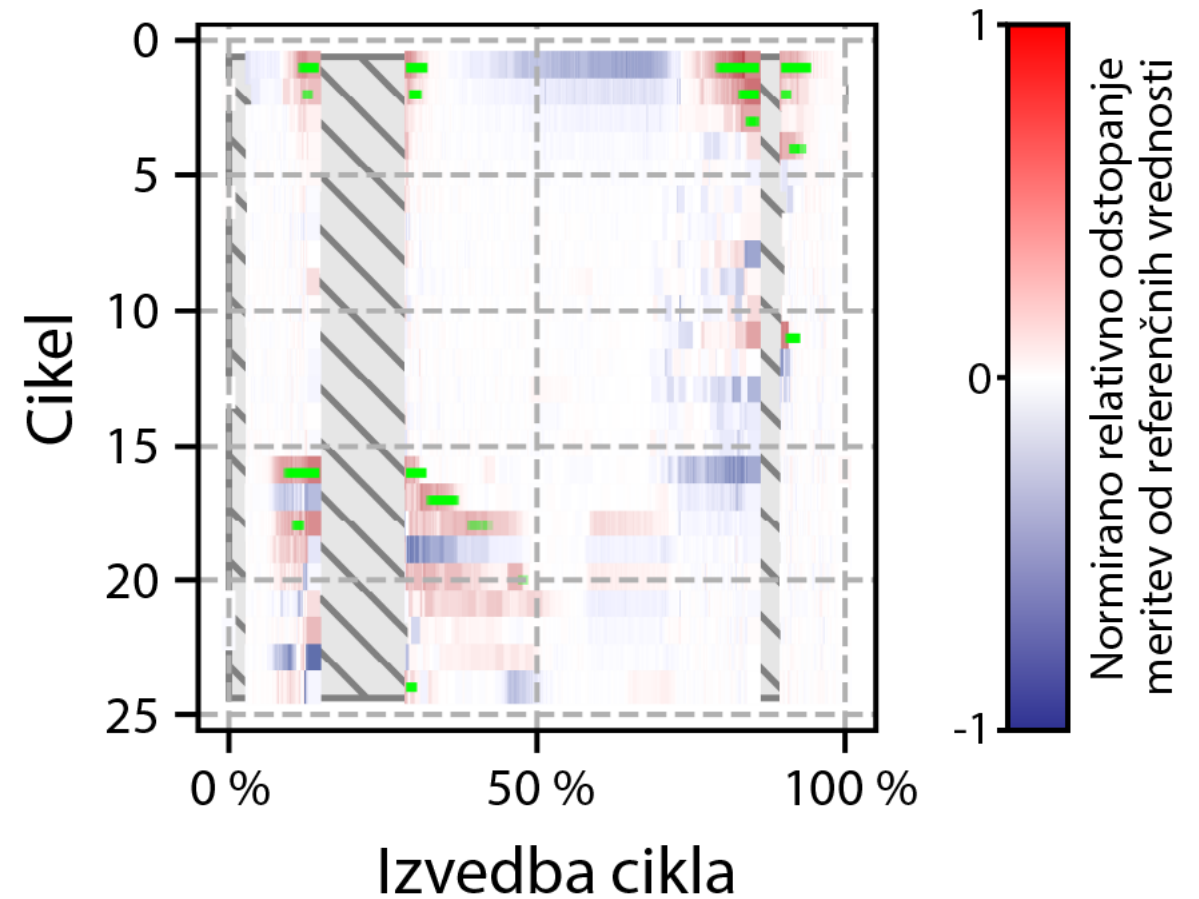
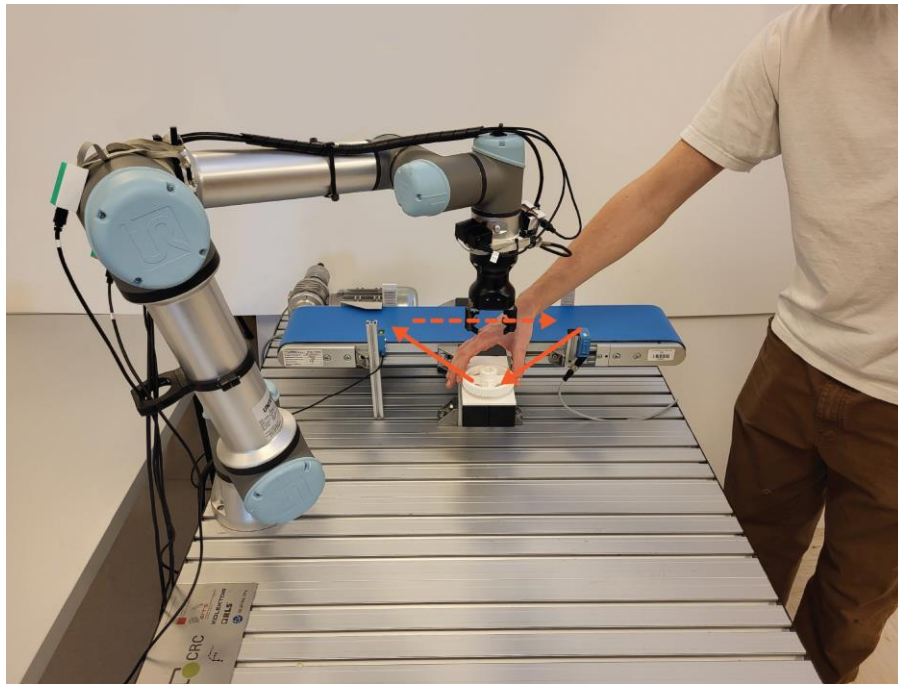


# Odziv na novo stacionarno oviro





# Sodelovanje s človekom



## Izvirni prispevki doktorske disertacije

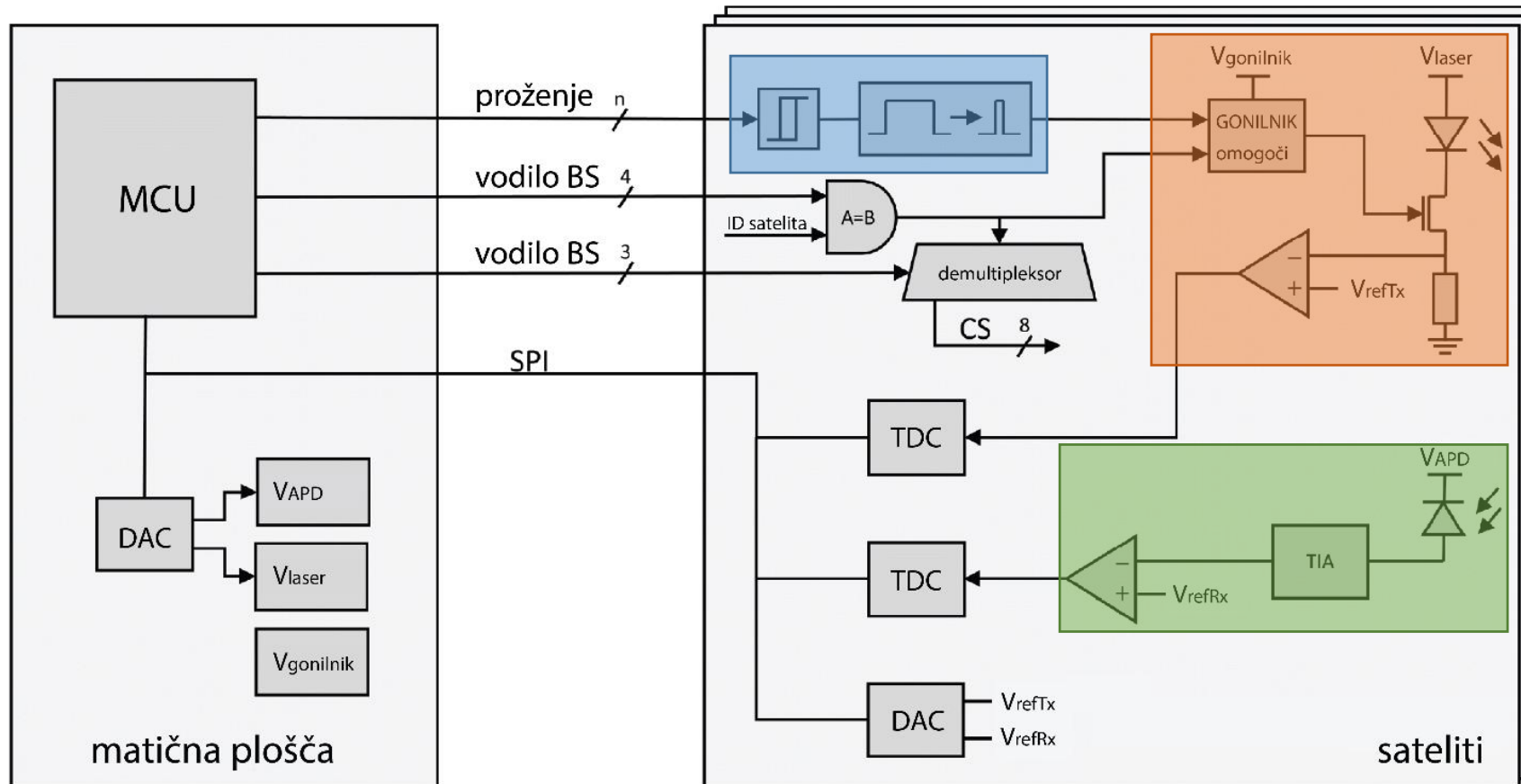
- Izdelan raziskovalni modularni lidarski sistem z možnostjo opazovanja internih signalov.
- Preučeni vplivi nečistoč na zrcalih na meritve razdalje z uporabo lidarja pri preusmerjanju svetlobe izven lidarjevega mrtvega polja.
- Preučeni vplivi zrcal iz sosednjih preusmerjanjih svetlobnih poti lidarja na meritev razdalje.
- Razvit učinkovit algoritem za določanje pripadajočih referenčnih vrednosti meritev ne glede na hitrost izvajanja robotskih gibov

Hvala za pozornost!

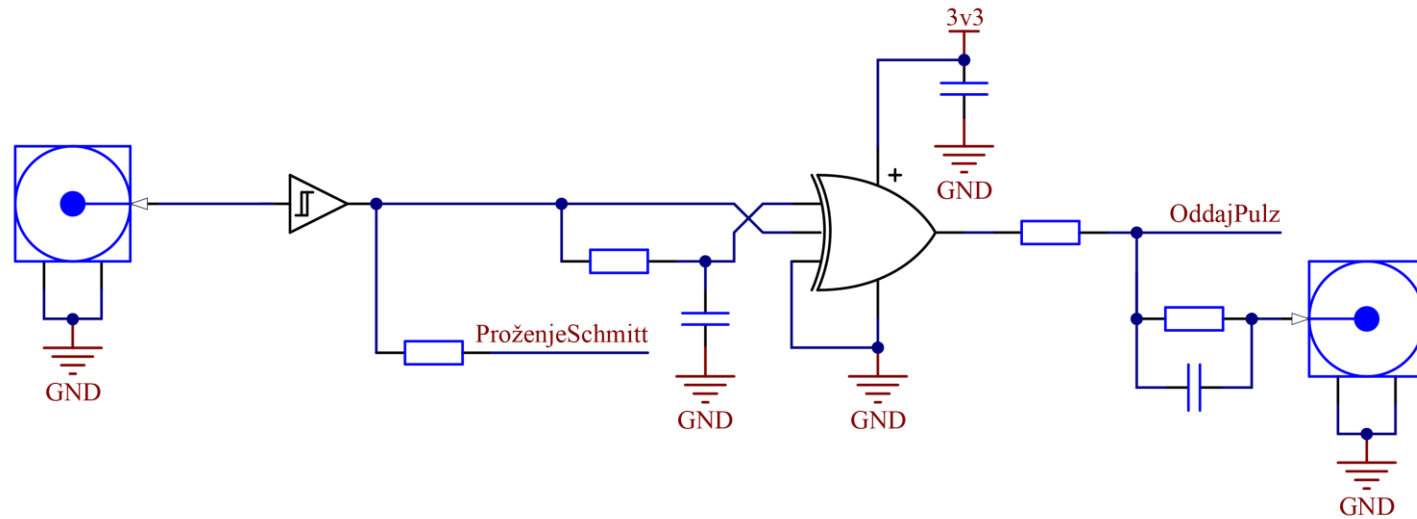


# Dodatne prosojnice

# Shematika lidarja



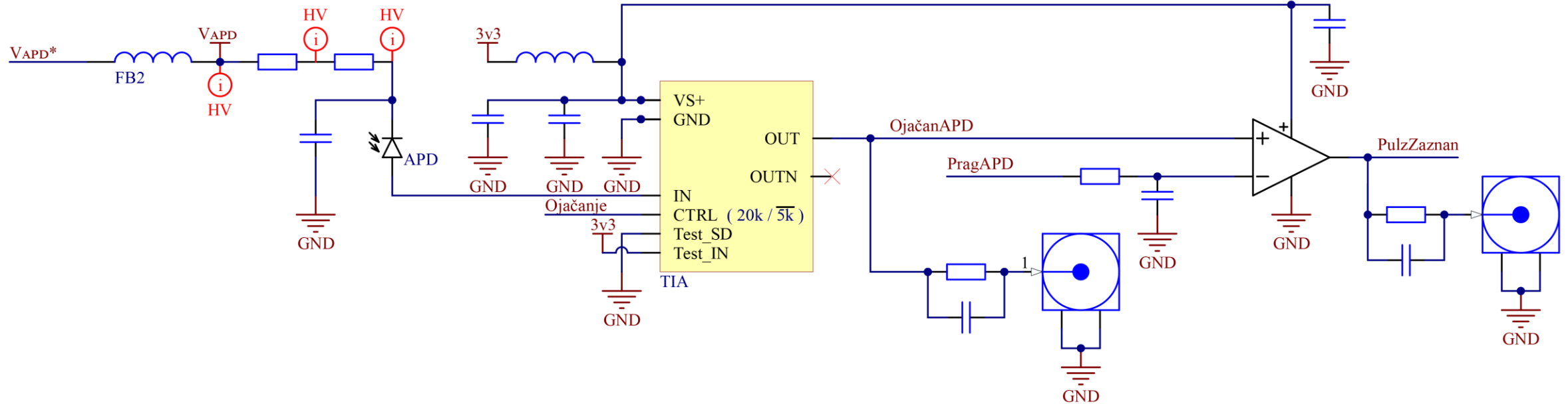
# Vezje za oblikovanje pulza



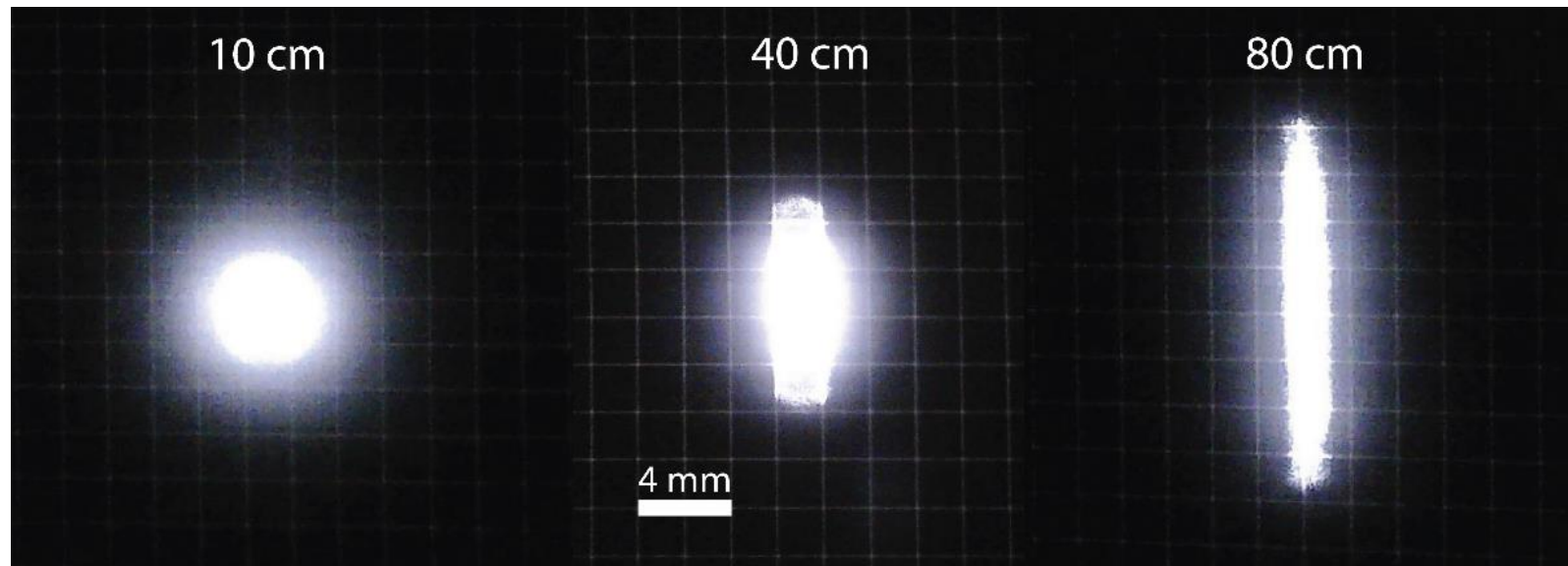




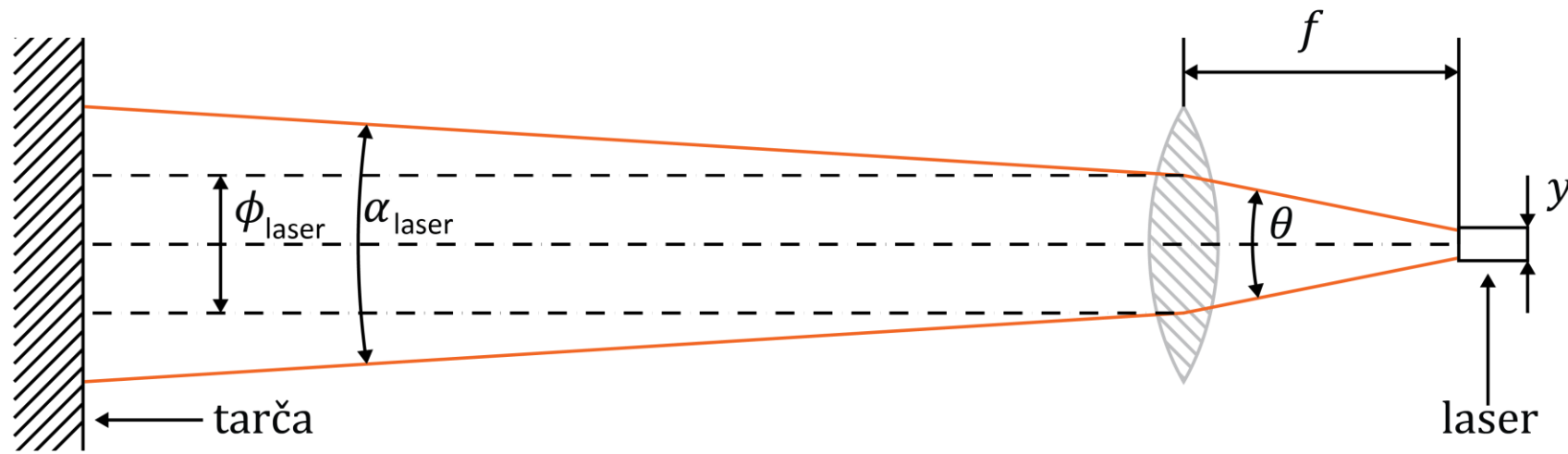
# Vezje za sprejemanje odboja



# Oblika oddanega snopa svetlobe



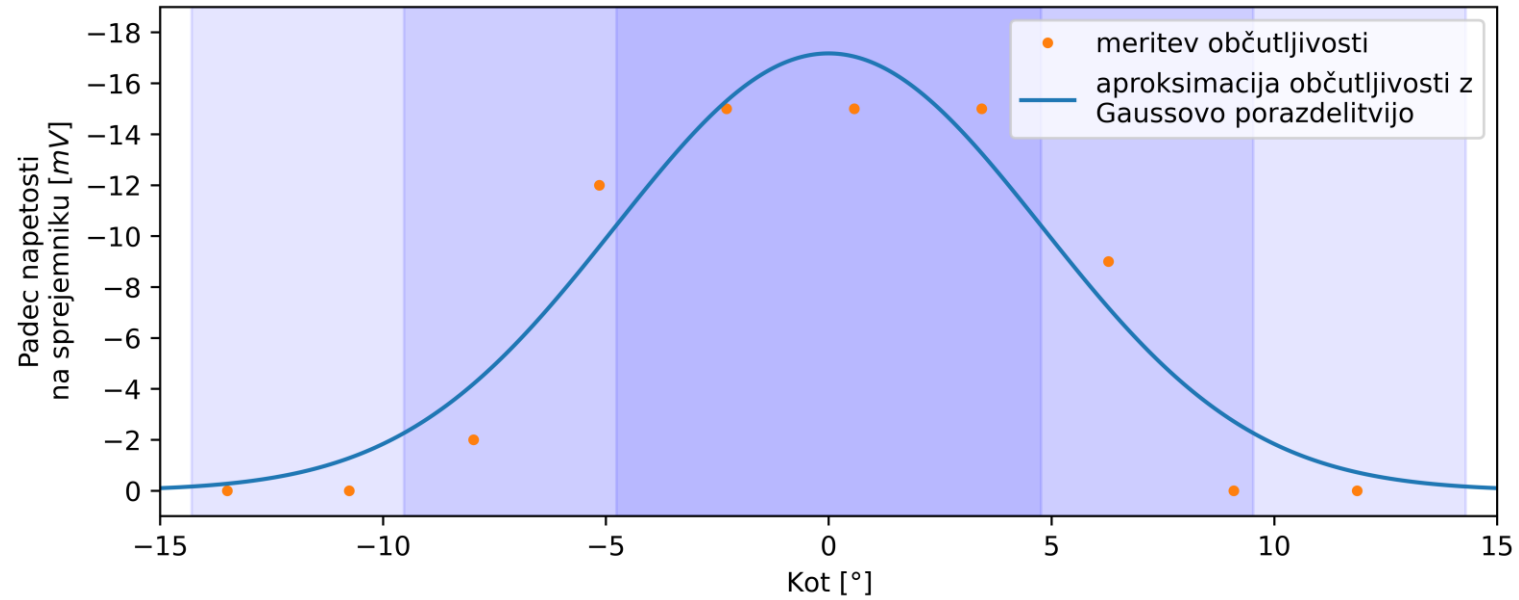
# Oblika oddanega snopa svetlobe



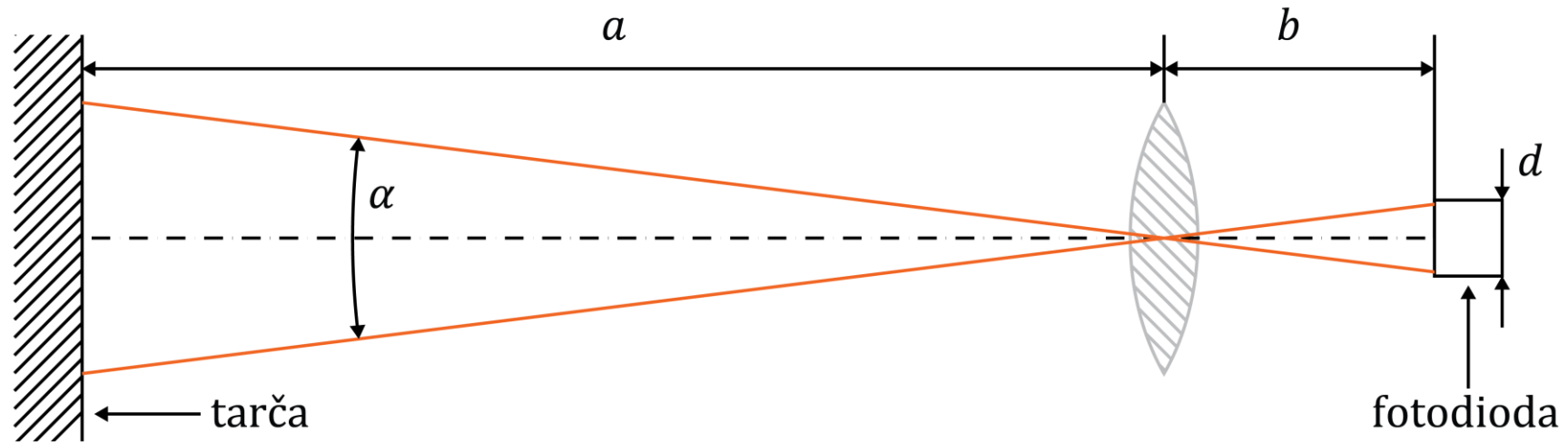
$$\phi_{laser} = 2 \cdot f \cdot \tan\left(\frac{\theta}{2}\right) + y$$

$$\alpha_{laser} = 2 \cdot \text{atan}\left(\frac{y}{2 \cdot f}\right)$$

# Vidno polje sprejemnika



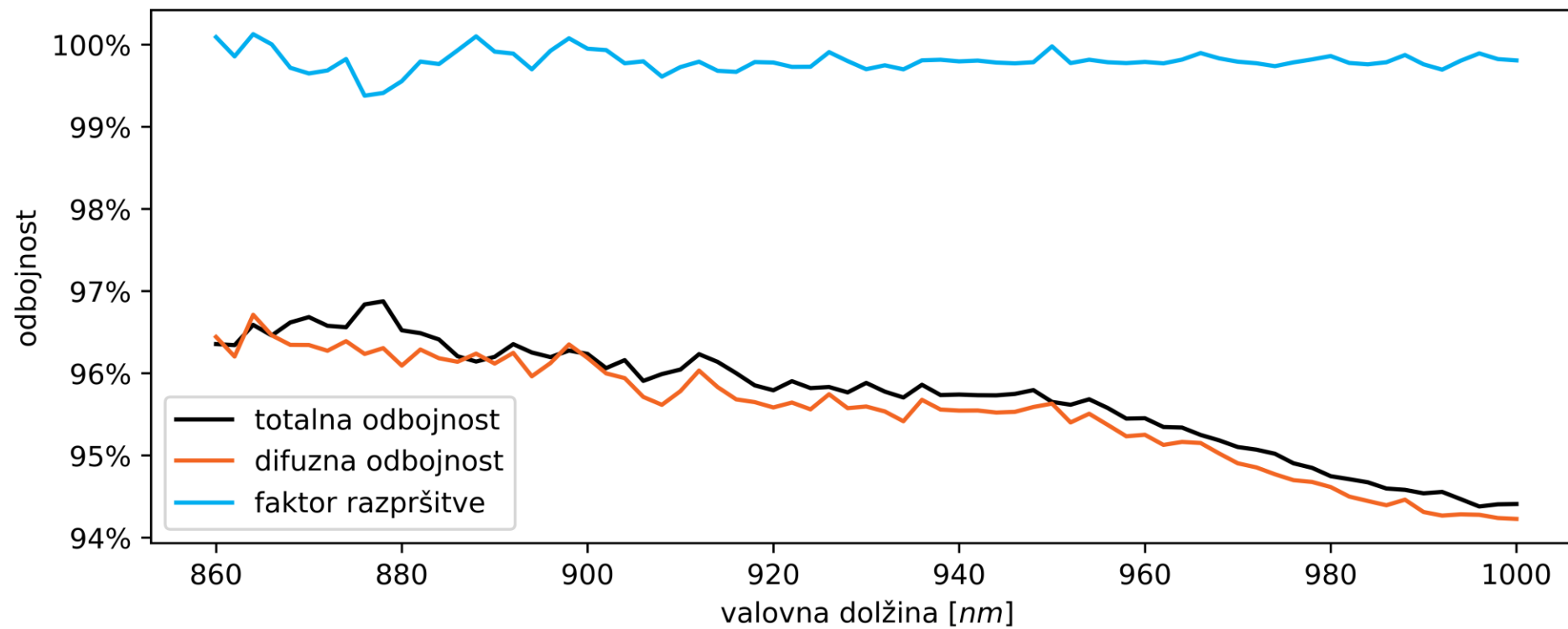
# Vidno polje sprejemnika



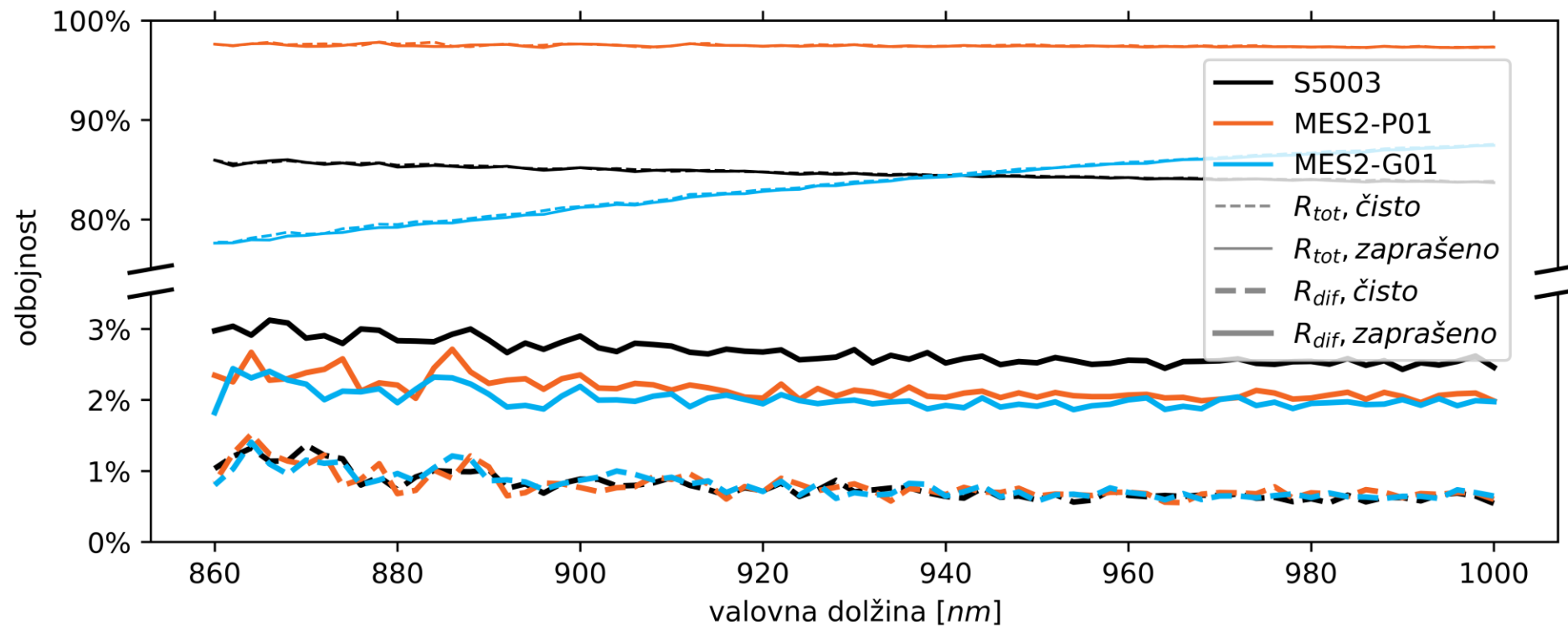
$$\frac{1}{a} + \frac{1}{b} = \frac{1}{f}$$

$$\alpha = 2 \cdot \operatorname{atan}\left(\frac{d}{2 \cdot b}\right)$$

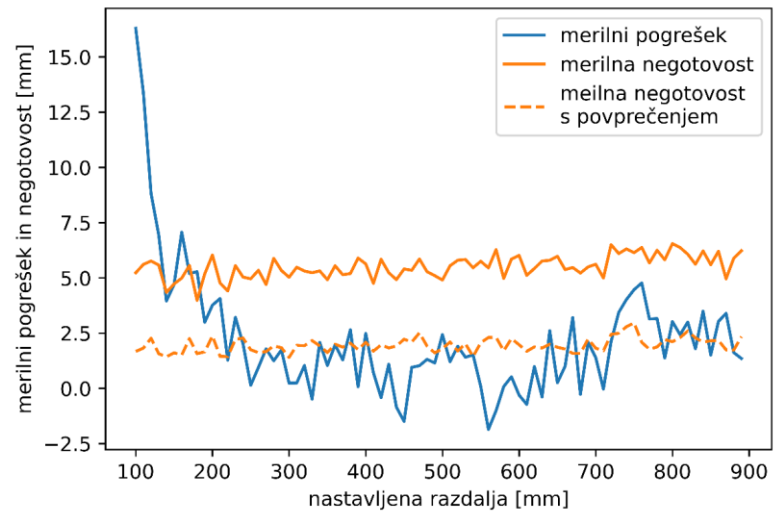
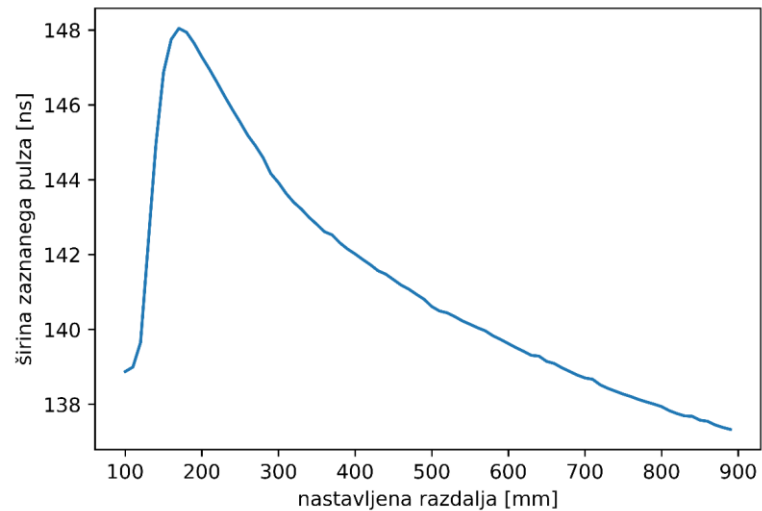
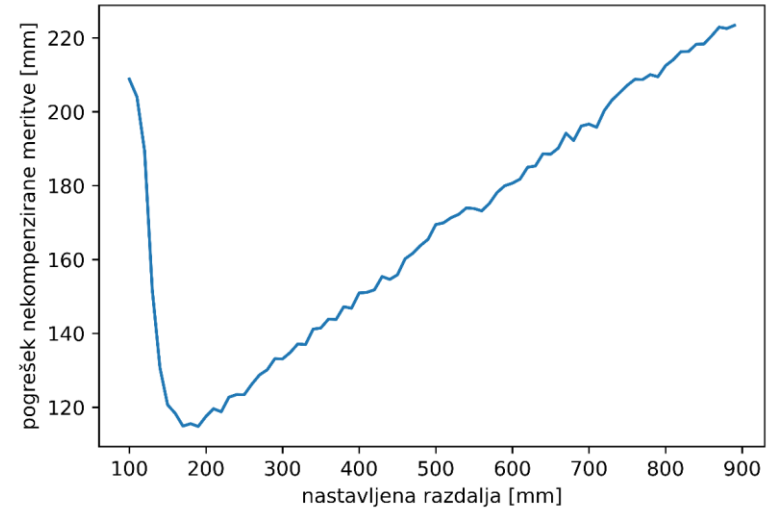
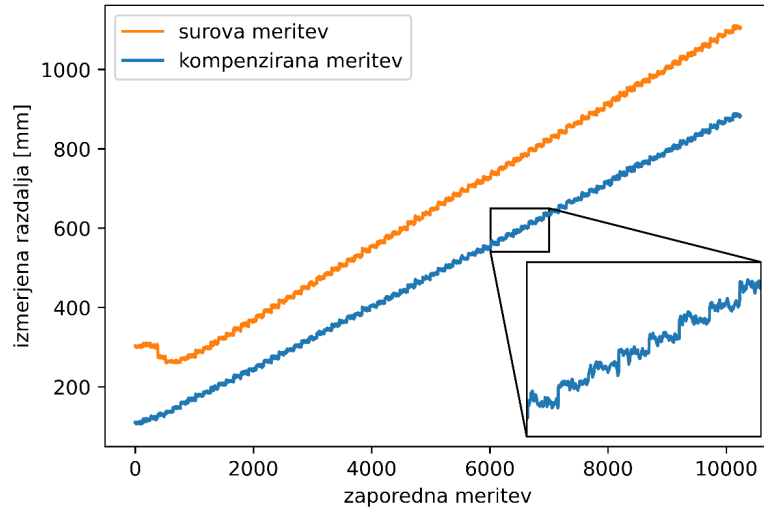
# Odbojnost tarče



# Odbojnost nečistoč na zrcalu

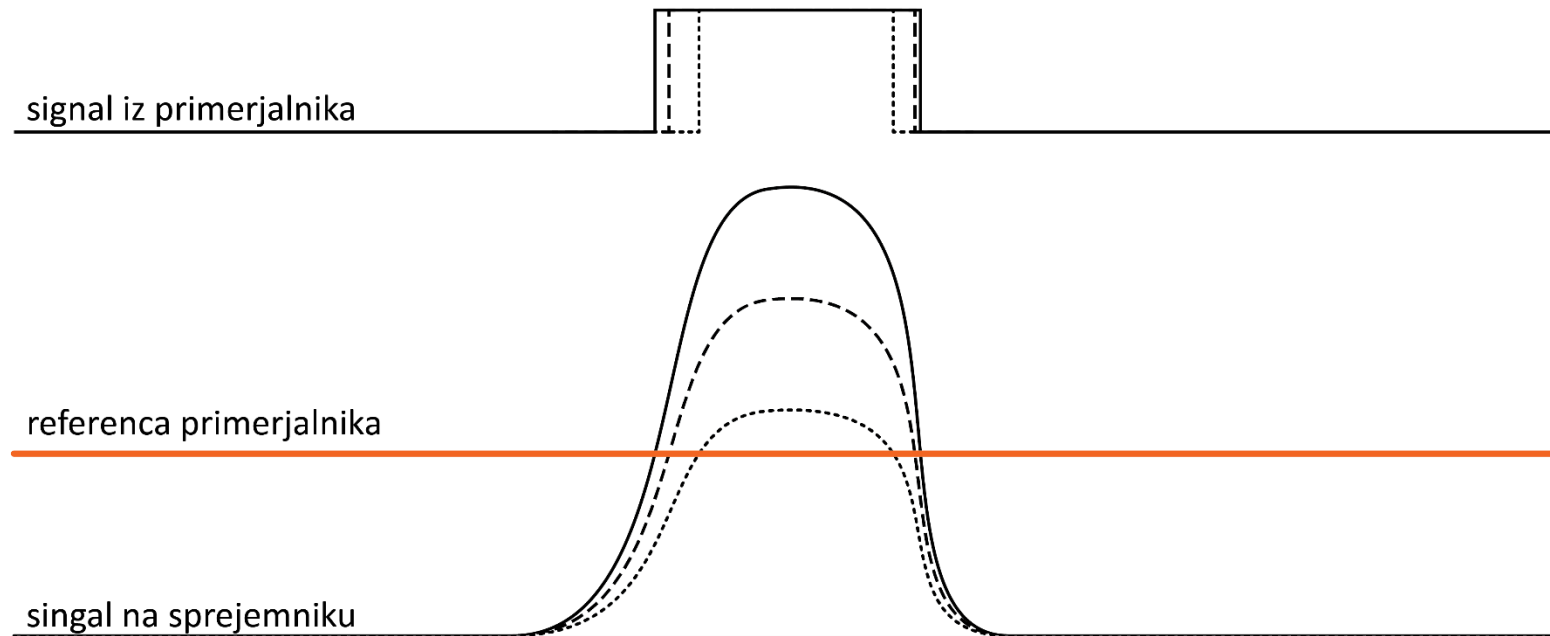


# Karakteristika izdelanega lidarja

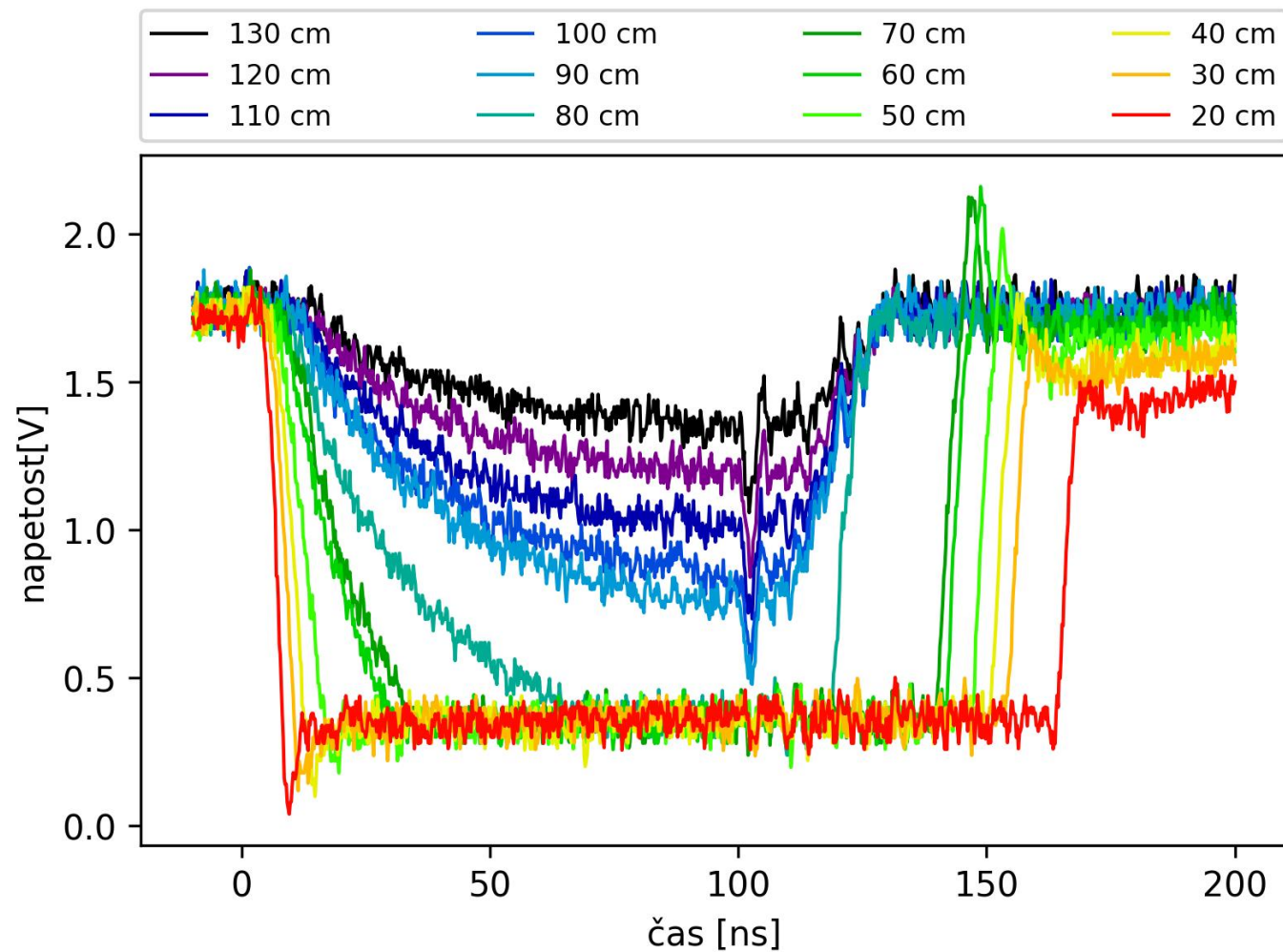




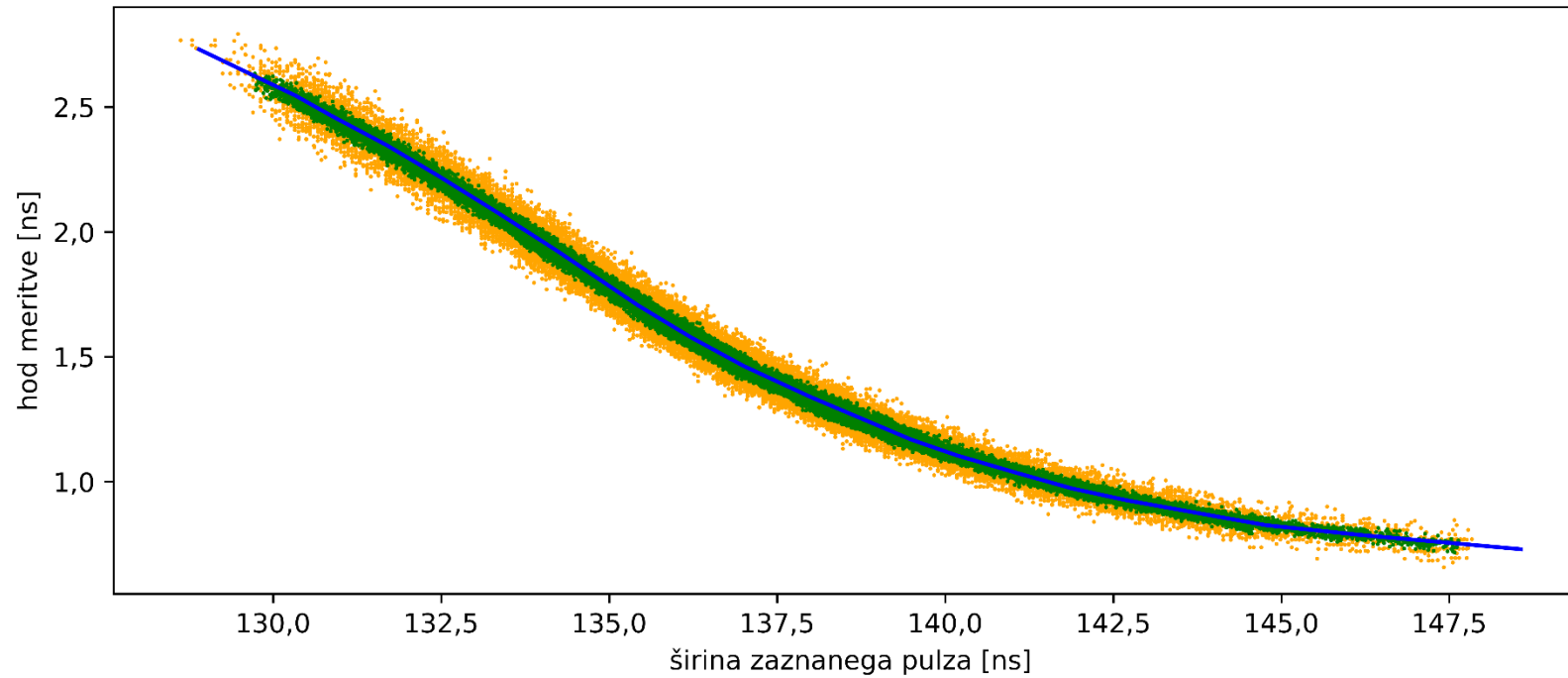
# Hod meritve



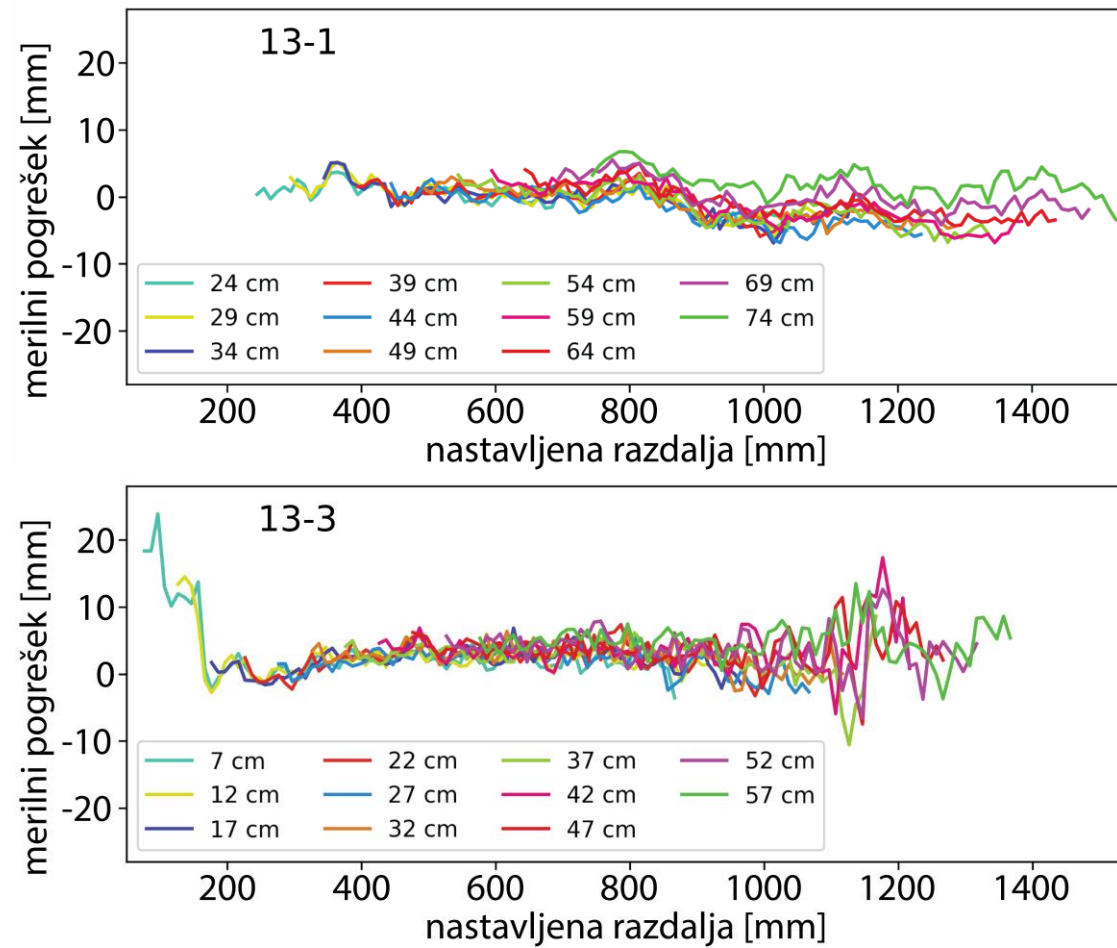
# Sprejemni signal pri čistem zrcalu



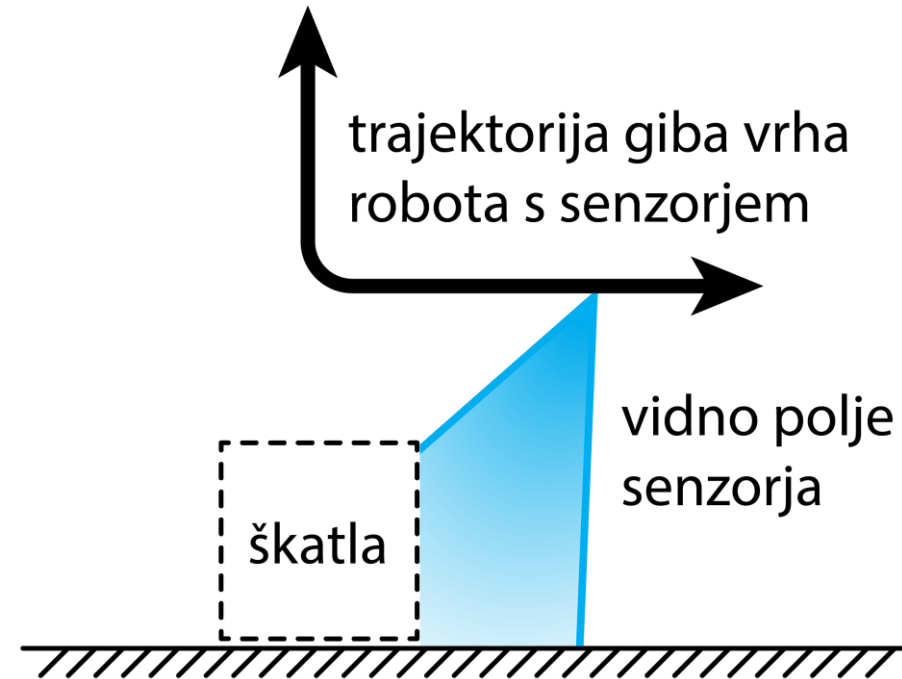
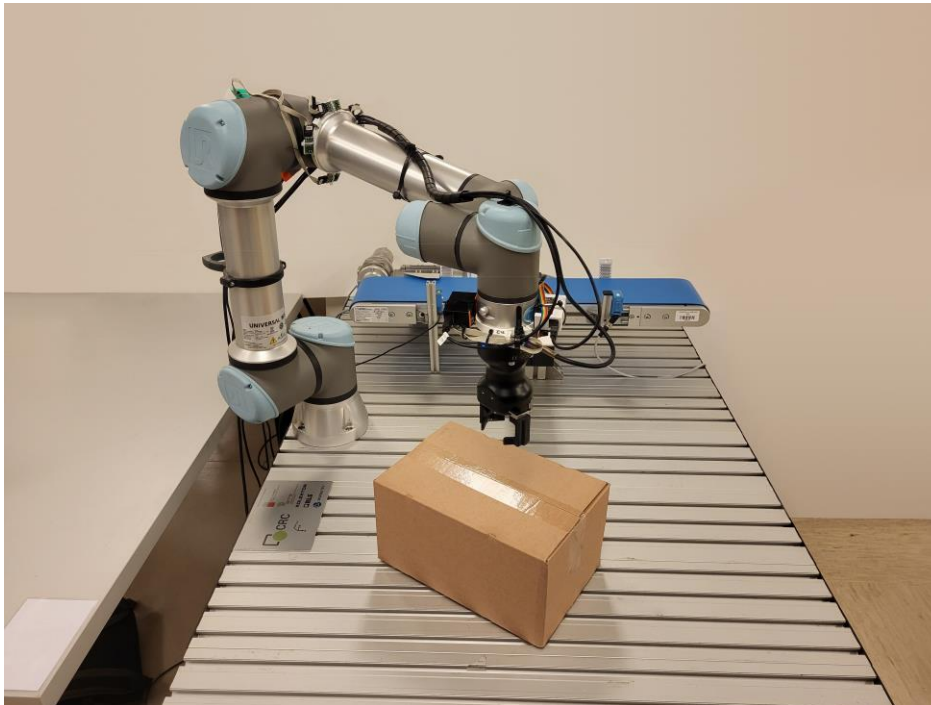
# Kompenzacija hoda meritve



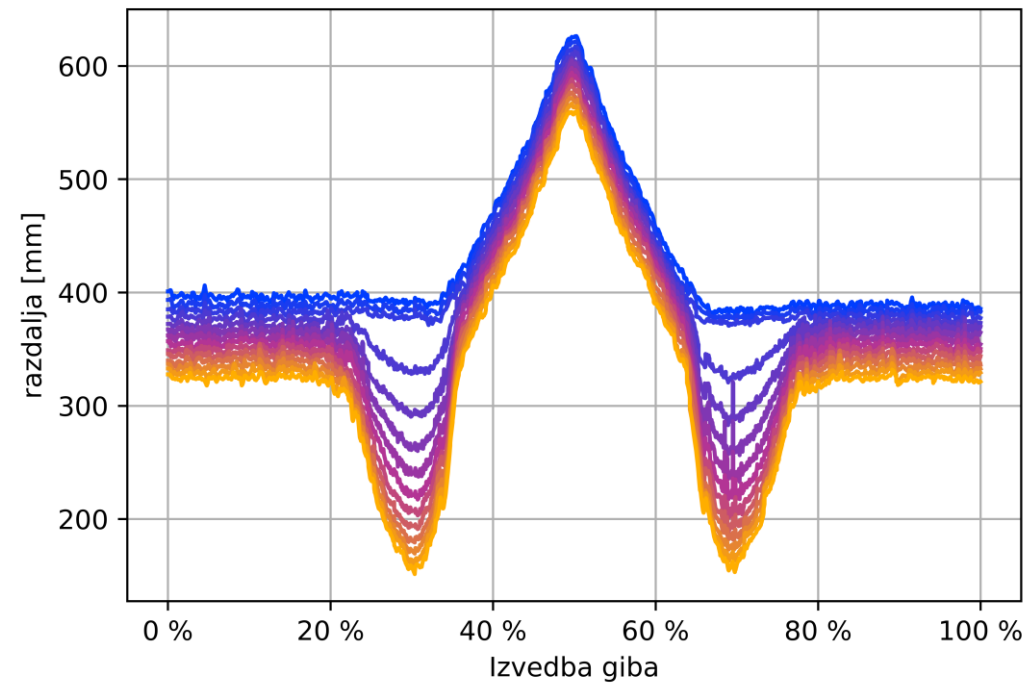
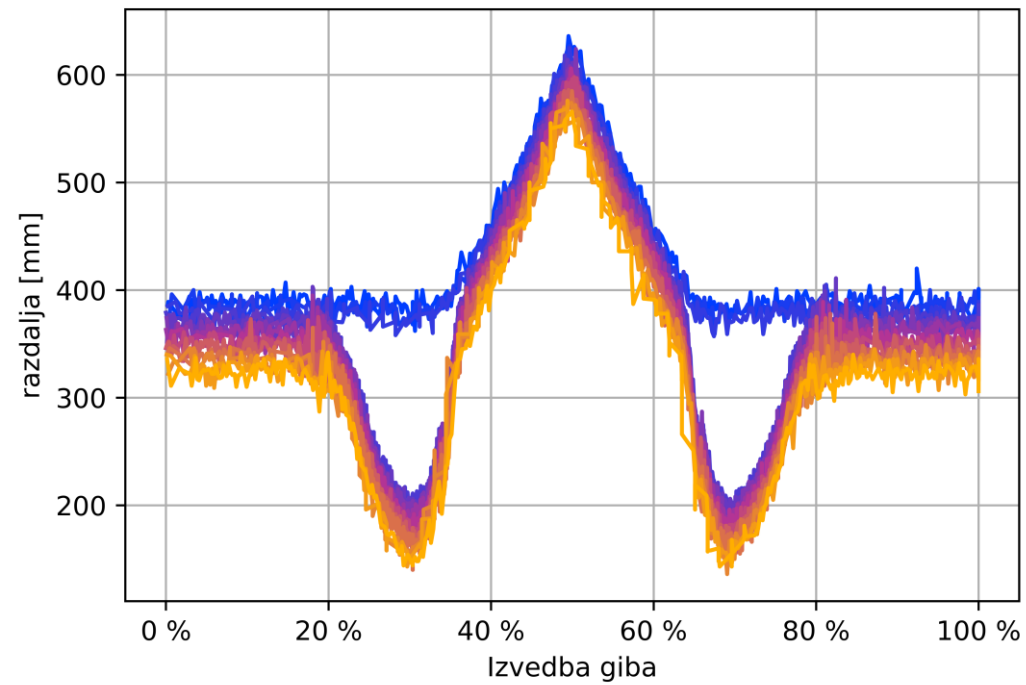
# Dva razmaknjena kanala – 1,3



# Primer preprostega giba



# Razdalje in referenca tekem preprostega giba



# Stanje tehnike – SICK Tim lidar

