Optimal pulse schemes for high-precision atom interferometry

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optical interferometer:
optical interferometer:

\[ |\psi|^2 = |\psi_1|^2 + |\psi_2|^2 + 2\psi_1\psi_2 \cos(\phi_1 - \phi_2) \]
optical interferometer:

\[ |\psi|^2 = |\psi_1|^2 + |\psi_2|^2 + 2\psi_1 \psi_2 \cos(\phi_1 - \phi_2) \]

atom interferometer:
atoms have mass
and internal structure
\[ \Rightarrow \text{couple to more external perturbations} \]
\[ (\text{gravity}) \]
optical interferometer:

\[ |\psi|^2 = |\psi_1|^2 + |\psi_2|^2 + 2\psi_1\psi_2 \cos(\phi_1 - \phi_2) \]

atom interferometer:

atoms have mass
and internal structure
⇒ couple to more external perturbations
(gravity)
laser couples between electronic states: absorbs photon momentum
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10 m atomic fountain at Stanford: ultracold $^{87}$Rb atomic cloud

Laser couples between electronic states: absorbs photon momentum

$$\Delta \phi = -2k_{\text{max}}gT^2$$

Army applications:
ultra-precise measurement of acceleration / gravity

- inertial navigation: submarines, autonomous vehicles —not jammable!
  - gyrosopes
  - gravity gradient sensors
- weapons system control
- geospatial mapping
- drone or satellite based detection of underground structures
10 m atomic fountain: sensitivity $10^{-13} \text{ g/}\sqrt{\text{Hz}}$

AOSense (2010)

$10^{-6} \text{ g/}\sqrt{\text{Hz}}$

state of the art

$10^{-9} \text{ g/}\sqrt{\text{Hz}}$
10 m atomic fountain: sensitivity $10^{-13} \text{ g/} \sqrt{\text{Hz}}$

factors:
- signal to noise ratio
- large momentum transfer

AOSense (2010)

$10^{-6} \text{ g/} \sqrt{\text{Hz}}$

state of the art

$10^{-9} \text{ g/} \sqrt{\text{Hz}}$
Apply optimal control to atom optics pulses

⇒ increase fidelity

⇒ robustness against fluctuations
Optimal pulse schemes for atom interferometry

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train of pulses $\Rightarrow$ rapid adiabatic passage:
tune through laser frequency at constant amplitude
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Optimize for fidelity

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optimize for robustness

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Conclusion

- optimal control can compress pulses by order of magnitude while guaranteeing robustness
- Army applications:
  - ultra-precise measurement of acceleration / gravity
  - inertial navigation,
  - satellite based gravitational sensing