MEMS Mirrors for Optical Tracking

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Abstract

The proliferation of small satellites and multi-satellite networks creates a necessity for accurate satellite tracking and ranging as well as high-speed, low energy communications.

This project seeks to:

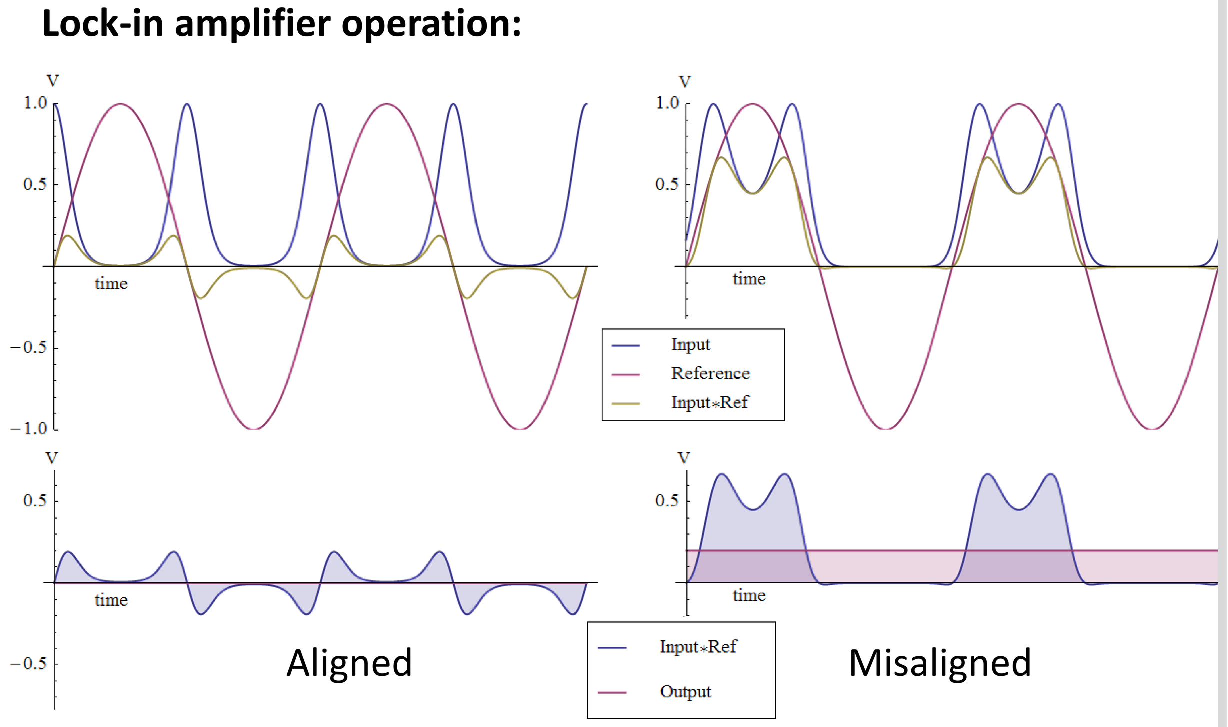
- Characterize the performance of microelectromechanical (MEMS) mirrors for tracking applications
- Evaluate the feasibility of a low-power optical tracking system operating on the principle of a modulated laser beam for use in optical communications, ranging, and high-precision time transfer.

Preliminary work focused on the characterization of commercially available MEMS mirror assemblies to determine their angular precision, linearity, and bandwidth. Subsequently, a two axis mirror was implemented in a bench-top feedback-controlled tracking system and optimized for low power and fast response time. The system was then configured to track a detector at a range of 20 meters and demonstrated robust tracking despite a signal to background ratio of -15db due to high levels of ambient lighting.

Operating Principle

- To track a target, the steering mirror is modulated to sweep a laser beam across the target's photodetector.
- Detector output is sent to a lock-in amplifier and decoded to a DC signal corresponding to the pointing error.
- Error signal is passed to an integrator which sets the DC bias on the mirror modulation to center the laser on the target.
- Since a lock-in is not sensitive to frequencies other than the reference, the laser can be simultaneously modulated and steered in both axes when appropriate modulation frequencies are utilized.

Lock-in amplifier operation:



Aligned

Misaligned

- Laser sweeps across the detector, causing variation in the observed light intensity.
- Photodetector signal serves as the input for the lock-in amplifier, along with a reference taken from the mirror modulation signal.
- Amplifier takes the product of the input with the reference and outputs a time-integral of that product.
- In the aligned case (left) peak light intensity is observed at the nodes of the modulation signal so the product of the input and reference cancels by symmetry.
- If the laser is misaligned (right) the location of the peaks is asymmetric leading to a non-zero output voltage.

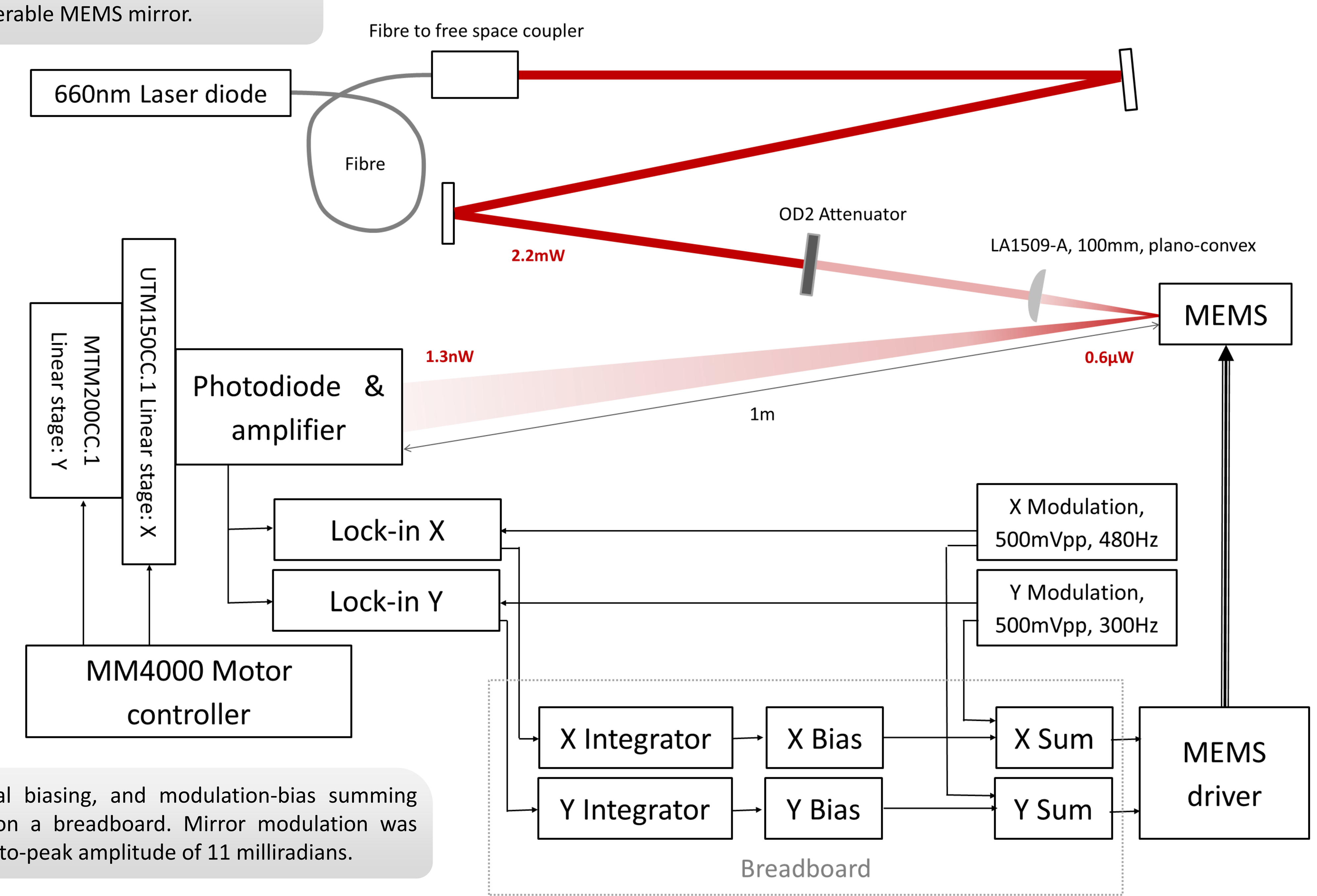
Bench-top system layout

A fiber-coupled diode laser is attenuated to microwatt intensities and focused onto a 1.2mm diameter, 2-axis steerable MEMS mirror.

The beam is subsequently allowed to diverge with a half-angle of 12 milli-radians before striking a 1mm² silicon photodiode connected to a 1MΩ transimpedance amplifier.

Two high-precision linear stages were utilized to move the detector.

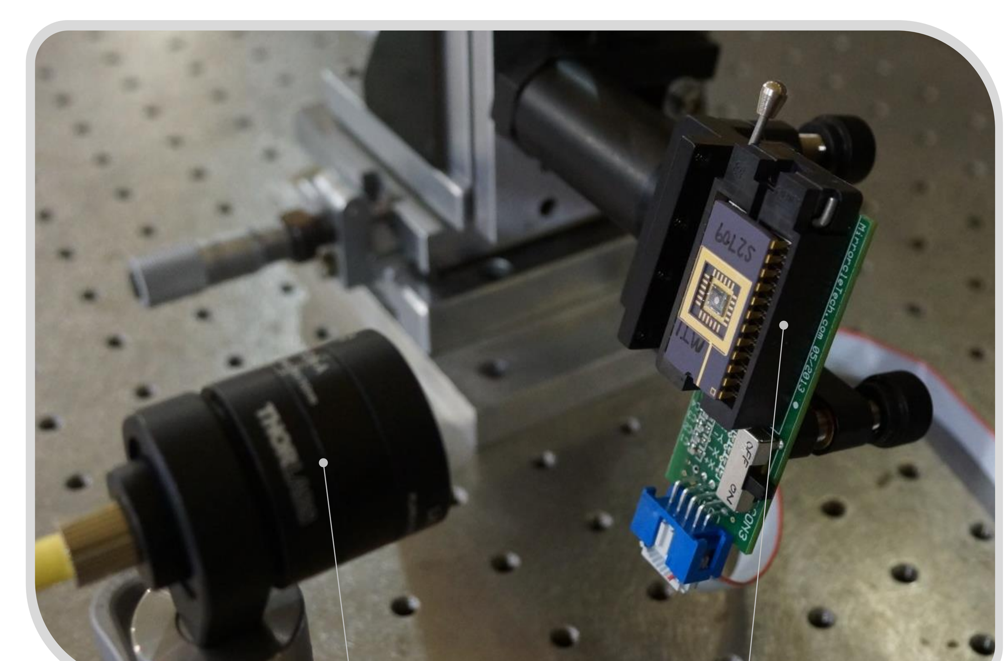
The integrator, manual biasing, and modulation-bias summing circuitry was set up on a breadboard. Mirror modulation was sinusoidal with a peak-to-peak amplitude of 11 milliradians.

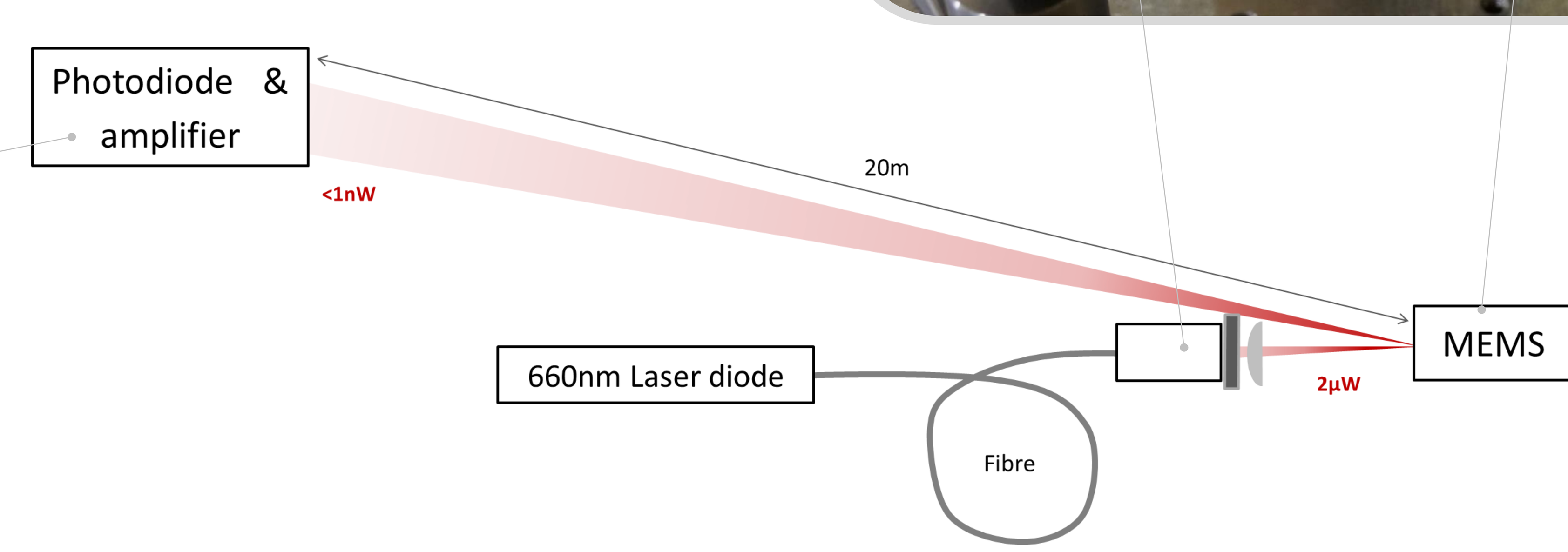


Long-range tracking

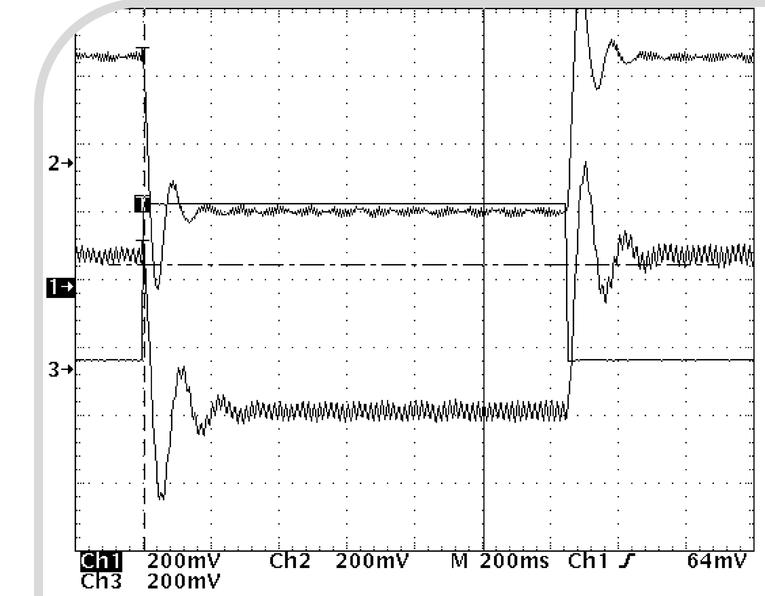
Essentially identical except:

- Reduced beam divergence (2.5 milliradian half-angle)
- Lower modulation amplitude (6 milliradians peak-to-peak)
- Photodiode is battery powered (due to layout constraints)





Results

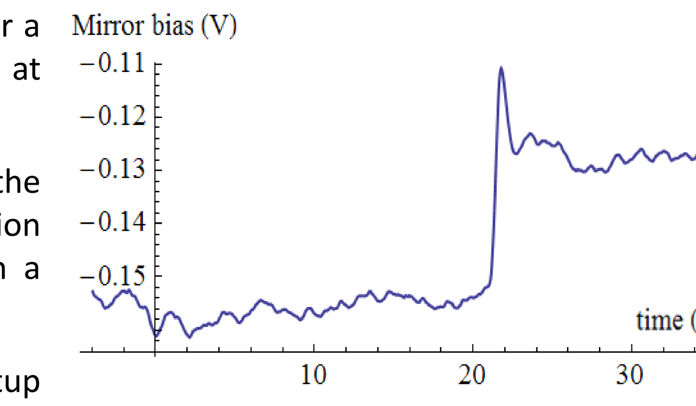


Step response:

- Low-frequency square wave error summed into the mirror bias.
- At nW detector illumination, optimal settling times of 200ms obtained for a 10 milliradian -equivalent step.
- Configuring the system to respond more rapidly is possible but sacrificed tracking robust-ness and increased noise susceptibility.

Sensitivity:

- Mirror bias compensating for a linear translation of 100μm at a range of 1m.
- It is important to note that the overshoot is due to the motion of the detector rather than a tracking error.
- Overall sensitivity in this setup was to within 10 microradians.

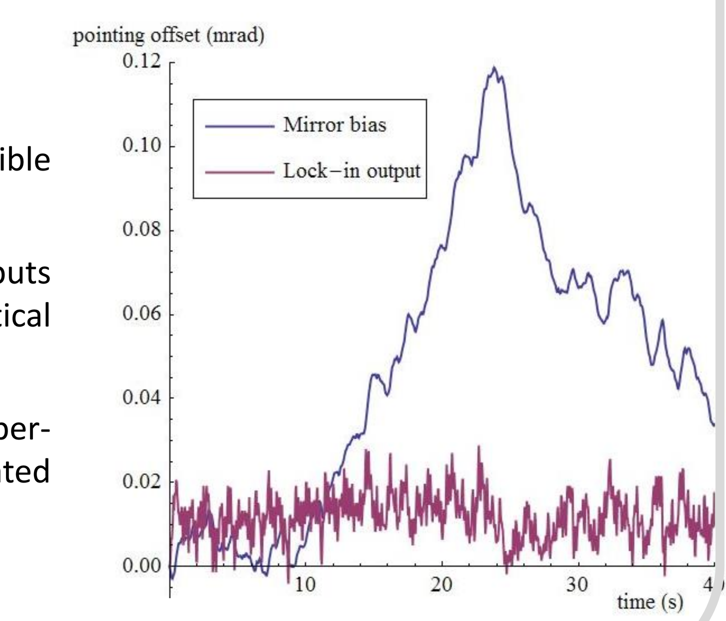


Mirror linearity:

- One of the two-axis mirrors was characterized to determine its linearity.
- Over a mechanical tilt angle of ± 12 milliradians, it was found to be linear in applied voltage with a coefficient of determination of 0.99995 in both axes.
- Repeatability was well within the 300 μradian precision of the testing setup.

Stability:

- Bench-top setup was susceptible to slow drift.
- Absence of drift in lock-in outputs suggests mechanical or optical instability.
- Using a temp.-controlled, fiber-coupled laser eliminated observable drift.



Conclusions

- Robust, low power, tracking was demonstrated with <1nW of detected power and a signal-to-background ratio of -15db.
- Tracking response rates were found to exceed requirements for most communications systems.
- MEMS mirrors possess sufficient linearity, bandwidth, and pointing repeatability to be well suited for optical tracking applications.

Further work

- Although one-way tracking has been successfully implemented, the ultimate goal is to create a two-way system in which each node is able to communicate its detector readings to the other via the tracking beam, thus allowing for isolated devices to locate each other and communicate.
- Algorithms need to be implemented in order to reestablish a tracking lock in the event that one is interrupted and to initially locate a detector and lock to it without manual steering.