MEMS dead actuator requirements

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Abstract

It is required for adequate ExAOC performance that no actuators in our controllable region be dead. We analyze the requirements on dead-actuator probability for the $N = 48$ configuration on a 64×64 MEMS device. For practical purposes, if the failure rate p is greater than 5 out of one thousand, a useable device most likely will not be produceable. For a reasonable chance (10%) that a random MEMS device is useable, we require a failure probability of 2.5 out one thousand.

1. Requirements

For ExAOC, we cannot have any "dead" actuators in our valid aperture. By a dead actuator we mean an actuator that is pinned to either a high or low displacement and which, as a consequence, scatters light throughout our point-spread function.

In this memo we focus on the $N = 48$ configuration for ExAOC, which has 45 actuators across the widest part of the pupil. The actuators inside the aperture number 1617. We also consider the actuators which form the first two rings of slaving around this aperture. With the first ring of slaved actuators, we now have 47 across the pupil, for a total of 1749. With the second ring, we have 49 across the pupil and a total 1885. Ideally none of these will be dead, but as a minimum we require that none of the actuators inside the aperture are dead. We allow the used actuators to be on any part of the MEMS device, such that there are always at least two actuators outside our useable area before the edge of the device. This gives us some flexibility in finding a useable area. For a reasonable probability of finding a successful device, we assign the probability of 10%.

2. Probabilistic model and simulation

Each actuator on the MEMS device is modeled as an independent Bernoulli random variable with a probability of being dead of p. For an $N \times N$ actuator MEMS device, this results in an expected number of dead actuators per device of of $N^2 p$.

We can easily calculate the probability that k specific actuators are not dead: $(1-p)^k$. When we have more than one valid aperture, Monte Carlo analysis is faster. For our Monte Carlo simulation, we generated many realizations of a failure profile for a 64×64 MEMS device. For each realization, we determined how many total actuators were dead, how many valid apertures existed with no dead actuators and consequently, if any valid apertures existed with no dead actuators. We did this in the $N = 48$ case for the aperture and the aperture expanded by one or two rings of slaved actuators. The Monte Carlo simulations were run for 10,000 trials.

By using many independent trials, and also assuming the Bernoulli model, we can estimate the probability that we have a useable device from the sample mean of the number of useable devices over all trails.

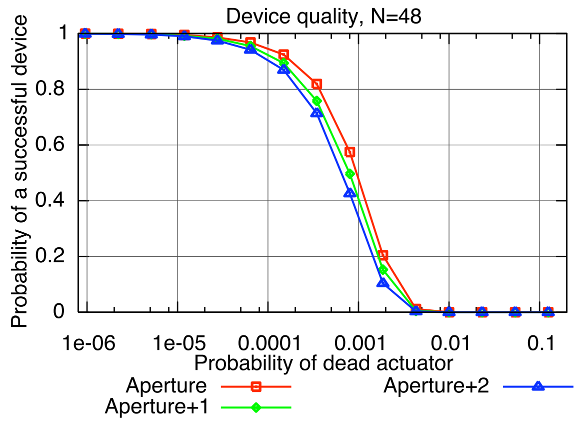

Fig. 1. Probability of a successful device as a function of dead actuator probability p, for a large range of p.

3. Results

First we consider the case of a single aperture position and use this to compare with the results of the Monte Carlo simulation. For a given k actuators, the analytic formula for the probability of the successful device is just $(1-p)^k$. We conducted this test for the $N = 48$ (45 across, 1617 total) and $N = 64$ (61 across, 2949 total) cases and the Monte Carlo results as a function of p agree very closely with the analytic formula. For a reasonable probability of a successful device, we can numerically find the root of the equation $(1-p)^k - .1 = 0$ as a function of p. For $N = 64$ we obtain $p = 0.00078$, or just fewer than 8 out of every ten thousand actuators can be bad. For the $N = 48$ case we obtain $p = 0.0014$, or 1.4 out of every one thousand actuators can be dead.

For the less-strict case that any valid aperture on the device is useable, we produce the following curves. Fig. **??** shows the three curves for the aperture and aperture plus one or two rings of slaved actuators. This plots the probability that a random MEMS device is useable versus the individual probability of any actuator being dead. Note that to achieve a high probability (greater than 90%) of a device being good, we require that p be less than 2 out of ten thousand. This level of actuator failure may not be achievable.

For the 10% probability of a successful device criterion, we need to examine a smaller portion of the curve, as shown in Fig. **??**. Based on these curves, for 10% probability of a successful device with the tight aperture, we need a dead actuator probability of $p = 0.0026$, or 2.6 dead actuators per one thousand. For the aperture plus the 2 rings of slaved to exist somewhere on the MEMS, this requirement is more strict: $p = 0.0018$, or 1.8 dead actuators per one thousand. Note that this curve changes rapidly with failure rate, but in all three cases for sizes of the aperture, a failure rate of five out of one thousand produces a very low probability of success.

4. Conclusions

ExAOC requires no dead actuators in our controlled aperture. For the $N = 48$ configuration on a 64×64 device we require an actuator failure probability p of less than 0.005. To achieve a 10%

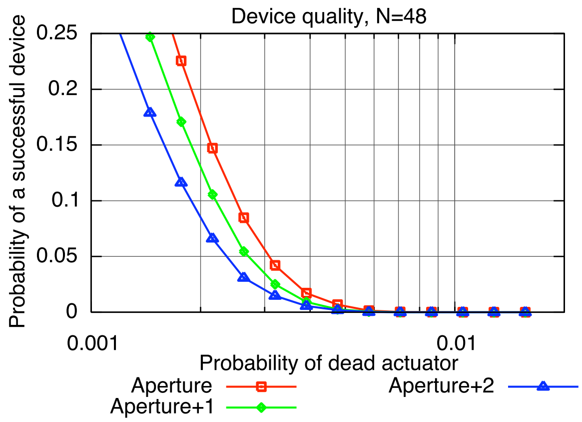

Fig. 2. Probability of a successful device as a function of dead actuator probability p, for a small range of p.

probability that a random MEMS device is useable, we require p to be 0.0026 for a tight aperture and 0.0017 for an aperture with two rings of slaved actuators around it.

Since we have used four 32×32 MEMS devices in the LAO, it would be useful to determine exactly how many dead (in the definition of this document) actuators there are (were) on each device. That would give us a rough estimate of the present failure rate p. At this point I would guess that p is around 0.01, which means that we need at least a factor of 2 and more like a factor of 5 improvement in the failure rate for a useable device to be produced.