# FAS-G PRELIMINARY STUDIES

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## INTRODUCTION

Conventional inclinometers, or analog tilt sensors, typically exhibit a slow response and cannot be used to track dynamic angular motion. Angular rate sensors can measure fast rotations, but they suffer from significant drift for slow and static environments. Inertial navigation units (INU's) can be used to overcome these limitations, but these are relatively large expensive. There is a need in a wide variety of applications to provide a small, low cost dynamic and static angular position sensor. MicroStrain, Inc (Burlington, VT, USA) has developed a new solid state dynamic and static inclinometrer called FAS-G. Employing micro-electromechanical (MEMs) sensors, FAS-G consists of a combination of two low-pass filtered accelerometers and two piezo-ceramic gyros. The University of Washington has been participating in the evaluation and validation of the device.

What makes FAS-G unique, is its ability to measure not only static postures, but also dynamic, fast limb movements. Through the use of the two accelerometers and two piezo-ceramic gyros and the requisite digital filtering and embedded software tracking algorithms, FAS-G provides dynamic response while maintaining the DC (static) measurement accuracy. As a result, during rapid angular movements, both posture and the dynamic components of movement can be accurately measured. This is not possible with conventional inclinometers based on fluidic electrolytes or DC response accelerometers.

The goal of this preliminary study was to test and characterize the performance of a device developed for accurately measuring both static and dynamic angular motion.

## METHODS

A prototype FAS-G device was built and various tests were performed to assess its measurement accuracy. The three tests included: 1) static angle measurement tests to assess the FAS-G's ability to measure static movements, 2) a pendulum swing test to assess FAS-G's ability for measuring dynamic movements, and 3) an impulse test to measure FAS-G's dynamic response during highly dynamic movements.

***Static Tests.*** To characterize the performance of the FAS-G for measuring static movements, a FAS-G and inclinometer were attached to an angular potentiometer, and various movements were performed. In 0°, ± 30°, ± 60°, ± 70° and ± 80° of roll, the FAS-G, inclinometer and angular potentiometer were rotated, at a slow rate (> 10°/s), between 0° and 360° of pitch. The data from the FAS-G and potentiometer were collected and stored at 100 Hz on a portable computer instrumented with a data acquisition card (Model AI-16-16E-4; National Instruments, Austin, TX). For each roll position, the angle outputs from the FAS-G, inclinometer and angular potentiometer were compared over the 360° movement range. The angle measurements from the potentiometer were considered to be the Gold Standard.

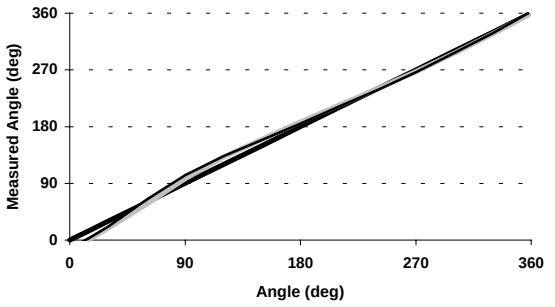
***Dynamic Tests.*** To characterize the performance of the FAS-G for measuring dynamic movements, the FAS-G, inclinometer and angular potentiometer were connected to the origin of a pendulum and various dynamic movements were performed. The pendulum arm was 30 cm long with a 500g mass attached to the end of the pendulum arm. With the pendulum, swinging movements, between ± 45° of pitch, centered about 180° of pitch, at angular rates up to 400°/s were performed. The data from the three instruments

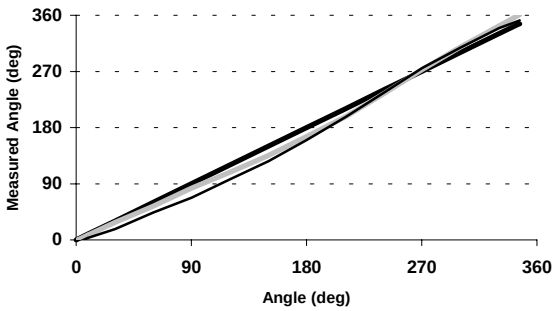
were simultaneously recorded at 1000 Hz and stored on a portable computer. For the swinging movements, the angle outputs from the FAS-G and inclinometer were compared to the angular potentiometer (Gold Standard) with respect to time. This allowed the comparison of dynamic angle measurements both in absolute terms and in the time/phase domain, so any differences, if present could be identified.

***Impulse Tests.*** To characterize the performance of the FAS-G for measuring highly dynamic movements, impulse tests were performed with the same pendulum apparatus. The FAS-G, inclinometer and potentiometer were attached to the pendulum; swinging movements were performed with the pendulum; and during the third oscillation, the pendulum was grabbed and abruptly stopped at approximately 180° of pitch (bottom of the pendulum down swing). Data from the three instruments were simultaneously recorded at 1000 Hz and stored on a portable computer. During the oscillating movements, the angle outputs from the FAS-G and inclinometer were compared to the angular potentiometer (Gold Standard) with respect to time.

## RESULTS

***Static Tests.*** Figure 1 shows the angle-angle plots comparing the outputs from the FAS-G, inclinometer, and potentiometer over 360° of pitch at - 70°, + 70° and 0° of roll. The angle output of the potentiometer (thick black line) was considered to be the Gold Standard, any deviation of the FAS-G or inclinometer from the thick black line represented measurement errors. As can be seen in the figures, the FAG-G and inclinometer performed well for measuring angles. However, at the operational limit of the FAS-G and inclinometer (± 70° of roll), slight measurement errors were seen. Overall, the FAS-G performed well for measuring static angles and typically, the performance of the FAS-G exceeded the performance of the conventional inclinometer.



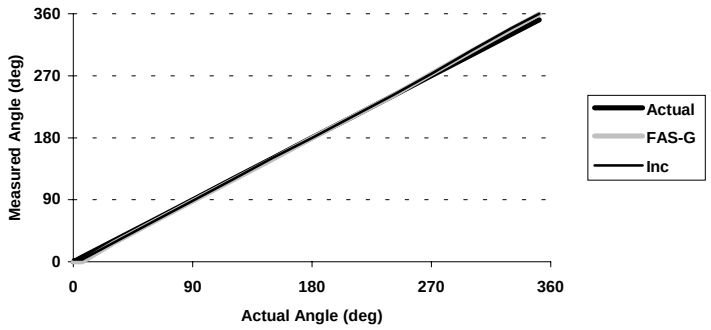



**Figure 1** Comparison of outputs between the potentiometer (Actual), FAS-G and inclinometer during 360° static angle measurement tests. Top two graphs represent the measurements of the FAS-G and inclinometer at operational limits - 70° and + 70° of roll respectively, and the bottom graph at 0° of roll. Typically, the performance of the FAS-G exceeded the performance of the conventional inclinometer.

***Dynamic Tests.*** Figures 2 shows a typical plot, with respect to time, comparing the outputs from the FAS-G, inclinometer, and potentiometer during the pendulum tests. The upper graph of Figure 2 shows the full test and the lower part the first three seconds. The angle output of the potentiometer (thick black line) was considered to be the Gold Standard, any deviation of the FAS-G or inclinometer from the thick black line represented measurement errors. Figure 3 plots the outputs of the conventional inclinometer and FAS-G as a function of the potentiometer angle. As can be seen in the figures, the FAS-G tracked the dynamic swinging movements quite well, whereas the conventional inclinometer both lagged and underestimated the magnitude of the movements.

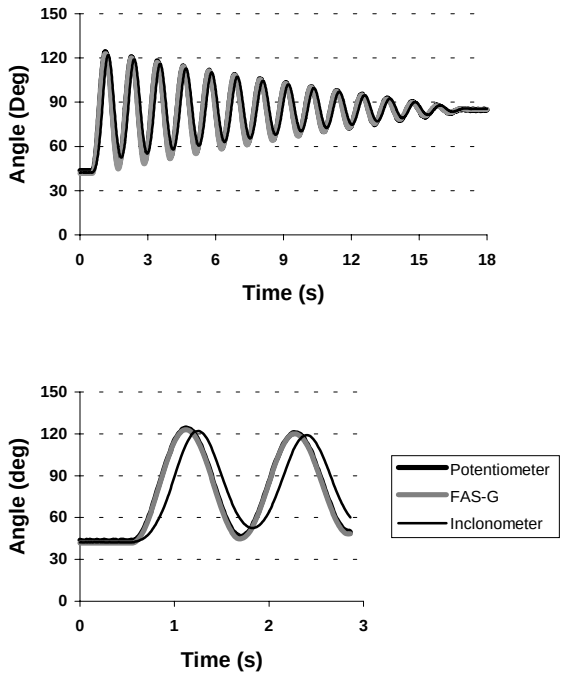



**Figure 2** Comparison of outputs between the potentiometer, FAS-G and inclinometer during a typical pendulum test. The FAS-G virtually tracked the dynamic swinging movements as measured by the potentiometer (Gold Standard), whereas the conventional inclinometer both lagged and underestimates the magnitude of the movements.

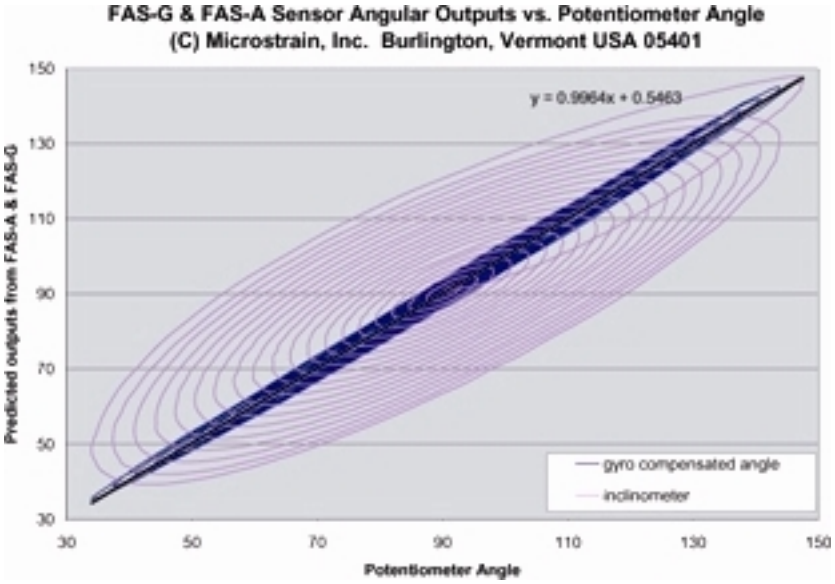



**Figure 3** This plot provides the FAS-G and inclinometer during a typical pendulum test, with these devices plotted on the vertical axis and with the potentiometer plotted on the horizontal axis. The conventional

inclinometer exhibits significant phase lag, as shown by the elliptical pattern, while the FAS-G tracked dynamic motion as measured by the potentiometer (Gold Standard).

***Impulse Tests.*** Figures 4 shows a typical plot comparing the outputs from the FAS-G, inclinometer, and potentiometer during the highly dynamic impulse test. The upper plot of Figure 4 shows the full test and the lower part shows the impulse region of the test (when the pendulum was abruptly stopped). Velocity is shown as a fine light gray line in the figure. The angle output of the potentiometer (thick black line) was the Gold Standard, any deviation of the FAS-G or inclinometer from the bold line represented measurement errors. As can be seen in the Figure, when the pendulum was stopped, the FAS-G tracked the potentiometer quite well during the highly dynamic impulse. In contrast, the inclinometer both lagged the movement and took a longer amount of time to settle.

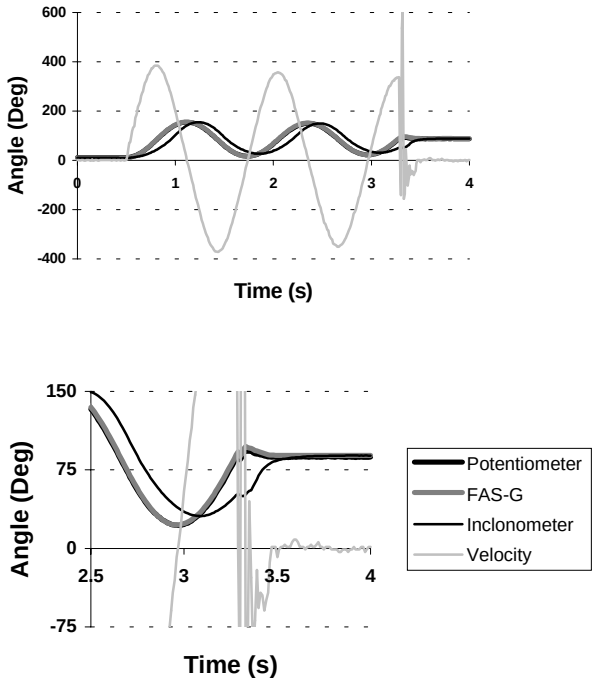



**Figure 4** Comparison of outputs between the potentiometer, FAS-G and inclinometer during a typical, highly dynamic, impulse test. The pendulum was rapidly stopped at roughly 3.3 seconds. This resulted in a large dynamic output from the angular rate (velocity) sensor. The FAS-G tracked the movement during the highly dynamic impulse quite well, whereas the inclinometer both lagged and took a greater amount of time to settle after the abrupt stop.

## DISCUSSION

Preliminary studies look promising for the use of the FAS-G as both a static and dynamic posture measurement tool. The FAS-G performed similarly to a conventional inclinometer for static angle measurement. However, during dynamic movements, the FAS-G was shown to be much more accurate in measuring angles in both absolute terms, and in the time domain (phase). The fact the FAS-G matched the

measurement of the potentiometer in the time domain, means it will very likely be suitable for measuring velocities and acceleration during dynamic limb movements. Movement velocities up to 400°/s were accurately measured. In addition, the impulse tests indicated the very abrupt movement changes may be accurately measured. As a result, FAS-G has the unique ability to measure not only static postures, but also dynamic, fast movements.