Illustrating High-school Physics Concepts using Microelectromechanical Systems

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Abstract

It has been widely demonstrated that students learn quickly, and are less likely to forget material when it is validated using a hands-on experimental approach. Young students are also interested in novel, high-tech applications, which they can understand. We have developed experiments using Microelectromechanical accelerometers and tilt sensors which demonstrate concepts of force and acceleration. The test experiments involve MEMS accelerometers, Game Boy, remote controlled or LEGO vehicles, and personal computers to allow students a hands-on approach to these concepts. Handouts involving the workings of the MEMS (tiny accelerometers made of Silicon) and SEM photos of the structures themselves are provided, along with a large-scale plexiglass model of the MEMS sensor, so that students can see how the MEMS sensors work. The experiments have been tested with high-school students enrolled in a summer research program at the University of California-Santa Barbara, and plans are in place to test the experiments with younger students (8^{th} grade) as well. The experiments have been well-received thus far, and students seem captivated by the small-scale nature of the MEMS sensors. These experiments were designed with a former physics teacher (co-author) to assure that correct content was being presented in a way in which students could easily learn.

Introduction

In addition to having impact in a broad range of applications, the proposed experiments will have a significant impact in lower-level education as well. The novelty of ultra-small machines and devices leads to new prospects for interesting middle school students in the physical sciences. Microelectromechanical devices encompass a few key ideas which capture students interest and serve as excellent science teaching tools. Some features unique to microsystems, include:

1. Size/Novelty
2. Gender Equality
3. Design flexibility

The mere idea that a working, functioning machine can be built which is smaller than the diameter of a human hair, or on the scale of the size of a few blood cells is inherently interesting to younger students. The idea that a secondary school student is able to do an experiment using, or actually designing one of these miniature devices is intriguing. In experiences giving small group demonstrations to early secondary school students, this was apparent. In demonstrations involving MEMS, the students wereimmediately drawn toward the "tiny machines you cannot see" [1]. Because the machines consist of a few, easily identifiable parts, it is easy to show a video or a magnified image of a device, and explain its function.

Size plays an important role in engineering and design. The size of a MEM device can be used to illustrate and gain a physical concept of the size of an object, and how that relates to its function. Young students can learn from example, that a tiny MEMS can detect changes in acceleration (sensor), yet MEMS devices will not be good at moving heavy objects (actuation). Scaling is an important concept in engineering, and MEMS can be a good tool to use when discussing these concepts. In many cases, having an actual example (be it on the internet, or in the classroom) is the key to retaining an idea.

MEMS are novel. Such novelty makes them a 'hot topic', one which is interesting to students of the upper secondary to lower high school level. It has been shown that middle school is the age when girls tend to be drawn away from science and engineering and more toward other career options [2,3,4]. To encourage more women to stay involved in science, the material has to be presented in a way that is exciting to both genders. MEMS devices are typically rather simple mechanically, at least to some degree. The elements are clearly visible, and in many cases can be explained at a level understandable to middle and secondary school students. Many MEMS have similarities in their mechanical systems, however are used for drastically different applications. This variety can be used to help interest students with a wide variety of likes/dislikes. A MEMS used as an automobile airbag accelerometer may be interesting to one student, whereas another might be drawn in by a bio-sensor which could function as an electronic 'nose'. MEMS are becoming widely developed for the medical industry, thus a blood pressure sensor, or a device used to pull on a blood cell and study its behavior may be of more interest. All of these applications are vastly different, however the MEMS share many elements which can be used to illustrate basic science principles determined to be important at the secondary-school level.

Experiments

For the first experiments, commercial MEMS parts were used. Due to the availability and simplicity, ADXL202 accelerometers were chosen. These +/- 2g accelerometers were obtained as free samples from Analog devices. We also purchased accelerometer test boards, which came with software to interface with a personal computer or laptop. This way, we could take the test boards to most any school, and either use the computers in the classroom, or bring laptop computers which would power the devices and utilize the output. A few simple experiments were designed using these components, as well as additional experiments that have been proposed and are in progress.

Equipment

The following equipment is needed for the MEMS experiments

1. Spring Scale with various weights
2. MEMS ADXL202 accelerometer chip, with the top of the package pried off
3. SEM's of the accelerometer chip (obtainable from authors if interested)
4. MEMS ADXL202 accelerometer test board with RS232 interface
5. Personal computer (any PC with RS232 connection)

6. Plexiglass model of the ADXL 202 (designed and fabricated at UCSB)
7. Nintendo GameBoy Color (or GameBoy Advance) with Kirby Tilt n Tumble game.

The actual worksheet used for the prototype MEMS exercise is included as Appendix A. When used in a classroom situation, each class would divide into five groups, preferably no more than 4 students per group. Each group would begin at one of the five 'stations' set up in the room. A summary of each station, and the learning objectives is given below:

Yellow Station: This station demonstrates the effect of gravity. It is a macroscopic, ordinary spring-scale, with weights to attach. It provides a hands on demonstration of the main concept behind the MEMS accelerometer. The MEMS accelerometer is just a proof mass, which changes position when it undergoes a force. In the case of these experiments, it can be affected by gravity just as a spring scale.

Green Station: The green station introduces students to the accelerometer test board. They have one or two ADXL202 test boards with accelerometers, as well as associated personal computers. In this station, the students tilt the accelerometer, and look at the output on the computer, therefore demonstrating the effect of gravity on the accelerometer, just as in the macroscopic spring-scale. Pictures are also provided, showing what the accelerometer looks like. In addition, a large-scale (15 inch square) plexiglass model of the MEMS is provided (See Figure 2), allowing students to see what is going on inside the MEMS chip.

Purple Station: The purple station expands on the material learned in the green station. In the purple station, students learn to think about acceleration, and sketch out the acceleration for a variety of real-life situations. This allows students to see the real-life implications of the MEMS accelerometers, and how they would be used to sense certain events.

Red Station: The red station is a brainstorming station. Now that students have an idea of how the device and similar MEMS devices work, this is an opportunity to think of uses for such a device. Past experience with younger students shows that they are very creative. Using creativity is sometimes overlooked in curriculum which focuses on learning specific concepts. In the physical sciences and engineering, creativity is very important, and should be fostered. The red station is to give students an opportunity to THINK.

Blue Station: The blue station is mostly for fun. In the future, this station will be fitted with accelerometer test boards, and made into a larger portion of the experiment. The blue station demonstrates a Nintendo Game Boy game (Figure 1) which uses an ADXL 202 as part of the game. Instead of using a d-pad to move the character around the video-screen, the accelerometer is used. Thus, to move the character around, you physically subject the gameboy to gravitational effects. It works surprisingly well. At this stage, students just get to try out the game and see another (hopefully interesting) application for the ADXL 202. However, in the future, this station will become a larger part of the experiment.

Figure 1. Game Boy Color used in experiment.

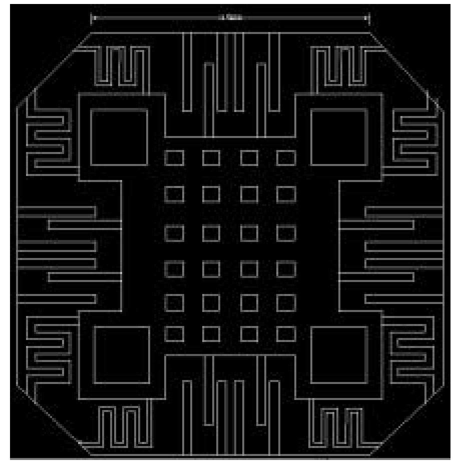

Figure 2. Schematic of Accelerometer used to demonstrate force and acceleration concepts.

Discussion

We use the MEMS components to provide a unique method of demonstrating concepts involving force, acceleration, and motion to students. Traditionally, engineering has significantly fewer females enrolled than their male counterparts. Various reasons have been investigated to this end [5,6], with one being that certain areas of science and engineering, are not appealing to female students. It has also been shown that young women tend to choose careers which have a human element. By using specially designed experiments, these gender issues can be addressed in a very non-invasive way. MEMS is useful to this end in the following ways. First, it is a very 'clean' technology. One must not get their hands dirty to participate. Actually the converse is true, one must take special measures to ensure that one does not contaminate the MEMS and cause failure to occur. In addition, MEMS devices can be used in many fields which directly influence, and help people. MEMS have been developed for use in hearing implants, drug delivery devices, other micro-surgical instruments, biosensors, etc, which all directly influence humans, and the quality of human life. Even the example device we are using in our test experiments, are used to trigger airbag deployment in automobiles.

Test Case

The above experiments (a subset of the above stations) were tested on a group of high school students who were at UCSB for a summer undergraduate research experience [7]. It was a group of 12 students, who had completed their sophomore and junior years of high school. This is not necessarily the target audience for these experiments, as these students were gifted/talented, and slightly older than the target, but provided a good test-bed for the experiments. Overall, the experiments were a success. A few issues were noted and corrected. In the initial experiments, there were only two stations. This caused the group size to be too large, not enabling all students an opportunity to get hands-on experience. In addition, creativity seems to be hampered when students are in large groups. Also, more direction was needed, which led to the creation of additional stations, providing students more direction in the beginning.

Future Work

Future work involves testing the experiments outlined above on a group of ninth grade physics students. This will most likely be done in the upcoming year in a local Santa Barbara high school classroom. We will also be upgrading our experimental equipment, so that more students will be able to participate.

In addition, we will be developing internet-based experiments, to reach a wider student base. These experiments will include teacher training, as well as video-enhanced experiments to demonstrate similar concepts.

Conclusion

MEMS has provided a fun and engaging way to demonstrate physics concepts to high-school students. An experimental set has been developed and tested, which demonstrates force, acceleration, and sensing concepts to secondary physics students. The experiments involve minimal equipment, and can be easily transported to schools to run the experiments. Future work involves the refinining of the existing experiments, as well as developing internet-based experiments for a wider distribution. We also plan to incorporate remote-controlled vehicles and/or lego vehicles into the experiments, so that student's thought experiments in the purple station can be tested. By using an innovative technology, such as microsystems, students are more interested, and see that engineering can have wide-reaching impact, something they may not have been exposed to thus far.

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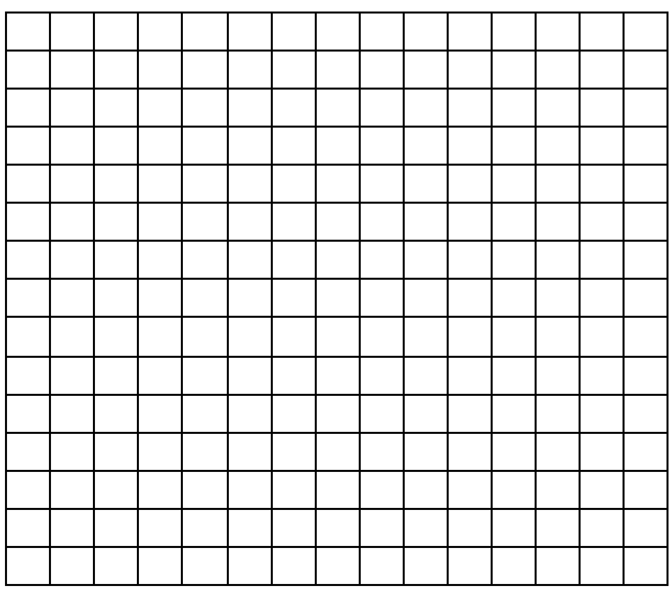
Appendix A. MEMS experiment worksheet (? Turner and Pearlman, 2001. Not to be used without written permission from the authors)

Begin at the table where you are currently sitting.

There will be some motion performed at the front of the room. On the axes provided, draw a distance vs. time graph of the motion you just saw. Pick an origin and decide which direction in the room is positive.



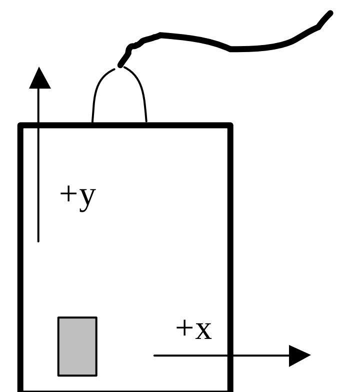
The Yellow Station

Here you will find a spring scale and some weights. Try out the equipment, discuss it with your group, and write down how you think it works.

What do you need to know about the spring scale in order to be able to paint those measurement lines on it. In other words, you know that when there is weight placed on the hook, the spring stretches, but what do you have to know in order to use this as an accurate measuring device?

The MEMS accelerometer has tiny springs and a tiny weight in it which compress and stretch when the device is tilted. The movement inside is also very tiny. Discuss with your group and write down how you think the MEMS might measure such tiny movements.

The Green Station



1. Here you will find a computer connected to a MEMS accelerometer on a test board. Make sure that the board is oriented like the one in the picture, with the cord facing away from you and the axes as shown.
2. The computer screen should show a set of axes, measuring acceleration in “g”s in the x and y directions.
3. Notice that the red and blue lines in the graph each stand for a different direction of movement, x and y.
4. While the accelerometer is lying still on a flat surface, click on the ZERO button. This should make the red and blue lines both travel along the horizontal axis.
5. With one hand, slowly and carefully tilt the accelerometer to one side, then to the other and watch the graph on the screen. Draw the graph it produces below using the appropriate colors.

6. Now tilt the accelerometer in the same fashion forward and back. Draw the graph it produces below.

7. Experiment with the accelerometer and answer the questions below:
    a. What is the largest angle that the graph will record?

    b. Does the accelerometer measurement or sensitivity seem different to you in either direction? How?

    c. Based on what you know about the MEMS accelerometer, is there anything that surprises you about how well it works?

The Purple Station

You experience acceleration in 2 dimensions (side to side and forward and back) when you ride in a car. Assume that you are in the passenger seat of a car at a red light and you are holding onto this accelerometer board. Sketch the acceleration graphs and label important features for the following scenarios:

a. the light turns green and the car moves down the street, turns right, stops at a stop sign, and then starts slowly again.

b. a suped-up hot rod pulls up in the lane next to your car and challenges you to a race. The light turns green and you peel out, continuously gaining speed

c. the light turns green but the car won't start and the car behind you hits your rear bumper

d. the light turns green and you make a left-hand turn right away, then gain speed down the street, then reach another stop light that just turned yellow

The Red Station

Now that you have a sense of what the MEMS device can do, brainstorm with your group about what it might be used for. First, list its unique qualities.

Then describe what it can do. Then come up with a minimum of three uses that you think might be possible.

Pick one of those uses and try to design how it might be made and used. Draw a labeled diagram and list what materials you would need.

The Blue Station

There is a GameBoy game called Kirby Tilt n'Tumble that uses the same MEMS accelerometer that is set up at the Green Station. SHARE!! Make sure everyone in your group gets a chance to try out the game.