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Engaging Community College Students in Earthquake Engineering Research with Smart Wearable Devices

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Engaging Community College Students in Earthquake Engineering Research with Smart Wearable Devices

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Abstract

Human beings live on the surface of earth. The motionless earth surface, in truth, is made up of enormous pieces of rock plates that are slowly but constantly moving. Those pieces continually collide with and rub against one another, and, at some point in time, their edges abruptly crack or slip to release the unbearable stored energy, creating earthquakes. History frequently reminds us how destructive earthquake can be. It is essential to better prepare before the next big one arrives. With the advancement of wearable technologies and internet-of-things (IoT), more and more powerful sensors are embedded into wearable devices, which provides the opportunities to use these emerging technologies to capture the earthquake ground motions for better designs of future structures and also for use in post-earthquake rescue. The California Community College System, with its enrollment of approximately 2.5 million students, is in a prime position to grow the future science, technology, engineering, and mathematics (STEM) workforce. Through a U.S. Department of Education funded Minority Science and Engineering Improvement Program: Accelerated STEM Pathways through Internships, Research, Engagement, and Support (ASPIRES) cooperative program between Cañada College, a Hispanic-Serving community college and San Francisco State University (SFSU), a public comprehensive university, a 10-week summer program is set up to provide opportunity for community college students to experience the excitement of the state-of-the-art research. As one of the Civil Engineering projects in this summer program, the community college students are working closely with graduate students at SFSU to evaluate the reliability and accuracy of the wearable device sensors comparing to traditional high-fidelity sensors, and to resolve the time synchronization challenge, a fundamental question on using the smart wearable device as seismic sensors. Systematic seminars and trainings are prepared as supplemental tools to help participating students get ready for upcoming challenges and provide them a meaningful research experience. The feedback from students shows that the ASPIRES program offers an effective way to engage students from community college in engineering research.

Introduction

Human beings, us, live on the surface of earth. The earth surface appears to be motionless, unchanging and dependable to most people. However, in truth, according to plate tectonics theory[1], the seemingly stable surface is made up of enormous pieces of rock plates that are slowly but constantly moving. Those pieces continually collide with and rub against one another, and, at some point in time, their edges abruptly crack or slip to release the unbearable stored energy, creating earthquakes. Although small ones happen every day around the world without people even feeling them, every so often, a big earthquake occurs and causes tragical destruction and loss of human lives. Plenty of examples can be found in the past. In 2011, the 9.0 magnitude Tōhoku earthquake caused 15,893 deaths, 6,152 injured, and 2,572 people missing, as well as 228,863 people living away from their home in either temporary housing or due to permanent relocation[2]. More than 86,000 people died in the 7.6 magnitude earthquake in Pakistani Kashmir in 2005[3]. The earthquake with magnitude of 7.9 in 2008 in Sichuan, China, took 88,000 lives[4]. Scientists can make reasonably long-term predictions, however, identifying the precise time frame and location of quakes is much more complicated and no successful story has been heard yet. Before researchers are able to find a way to predict earthquakes precisely in advance, and perhaps even control them, it is critical to better prepare before they hit. Many researchers devoted their efforts in utilizing structural control to reduce seismic responses of the structures[5-9]. However, the structural control is typically applied after the structures are designed. It will be beneficial to look at how to improve the performance of the structure being designed. In present design practice, structures are designed according to the building codes developed by building authorities, which use past earthquake records as one of the design bases. Currently, those earthquake records were mainly captured using seismic stations built around the world with high-fidelity sensors and equipment installed. However, due to the high construction cost and operating expense, there are limited numbers of seismic stations installed around the world. Because of that, only limited numbers of past earthquake ground motions are available. The more earthquake records available, the more probabilistically reliable predictions can be made on the performance of structures under such earthquakes. Therefore, there is an essential need to use newly emerging technologies for more comprehensive and accurate recording. With the advancement of wearable technologies and internet-of-things (IoT), more and more powerful sensors are embedded into wearable devices, which makes them a potential complementary source for recording ground motion. Existing research has validated that the accelerometers from a variety of smart mobile devices have the capability of recording seismic response with good fidelity[10-12]. The issue is that there is a need to develop a proper method for these sensors to distinguish noise, such as the vibration of a person's body, from excitations of different intensities in earthquakes.

Wireless sensor networks (WSNs) have become increasingly important in recent decades with the connectivity of the internet age. These sensors have a wide variety of applications. However, there are several challenges inherent to the use of WSNs. One of the most important has to do with the accurate telling of time by any given sensor. A smart wearable device is essentially a wireless sensor that inherits this challenge.

The California Community College System, with its enrollment of approximately 2.5 million students, is in a prime position to grow the future science, technology, engineering, and mathematics (STEM) workforce. Through a U.S. Department of Education funded Minority Science and Engineering Improvement Program (MSEIP): Accelerated STEM Pathways through Internships, Research, Engagement, and Support (ASPIRES) cooperative program between Cañada College, a Hispanic-Serving community college and San Francisco State University (SFSU), a public comprehensive university, a 10-week summer program is set up to provide opportunity for community college students to experience the excitement of the state-of-the-art research. The participating students are sophomore students who have no previous research experience and have at least one more year of courses to complete at Cañada College before transferring to a four-year university. As one of the Civil Engineering projects in this summer program, the community college students were working closely with graduate students at SFSU to evaluate the reliability and accuracy of the wearable device sensors comparing to traditional high-fidelity sensors, and to resolve the time synchronization challenge, a fundamental question on using the smart wearable device as seismic sensors.

Proposed Solution

Most wireless sensor devices contain individual clocks, which are just timers that use a crystal oscillator to keep time. Because each sensor has their own individual clock, there is potential for a phenomenon called clock drift. Clock drift refers to the fact that not all clocks have the exact same frequencies as each other. In other words, they do not count time at the same rate. As time progresses the clocks of two different sensors will drift apart from each other. Other problems related to time include delays from software and also content loss. It is possible that the content being sent by the sensors can simply not make it to the desired location. All of these problems relating to time result in data being unreadable and meaningless. The solution to these problems is termed time synchronization and it is clear why such synchronization is an important feature in WSNs. Time synchronization also allows movement, location, and proximity detection. The goals for these sensor networks can be achieved by a process that is formed by four steps: 1) send time, 2) access time, 3) propagation time, and 4) receive time. Send time is when the collected information from either wired or wireless sensors is sent to the master node of the system. Access time is the time it takes the master node to retrieve data from the connected sensor. Propagation time is also referred to as propagation delay because it is classified as the amount of time it takes for the information signal to travel from the sender to the receiver. Lastly, receive time is the time it takes for the master node, to receive and graph the data received from the sensor, either wired or wireless. The sum of all these times is called the offset between the two nodes. If the offset can be measured, then time synchronization can be achieved. To achieve this goal, the so-called Unix time is utilized. Unix time, measured in milliseconds (ms), is defined as the time that has elapsed since Thursday, 1 January 1970, and is therefore a rather large number. It provides a global time and common reference to the local sensor's timestamp during any given instance. The proposed method of time synchronization is implemented after the data has been collected (during post-processing), and therefore differs from common methods where time is synchronized and clocks are corrected within the sensors themselves. The proposed method reduces stress on the sensors, so it may be a more viable option for smart wearable devices, which are limited by processing power, memory, and energy capacity[13].

A wearable wireless sensing device, Shimmer3 ExG (http://www.shimmersensing.com, refers to Shimmer herein), as shown in Figure 1, was used in this study for data collection. Shimmer is adopted because it features a 3-axis accelerometer and 3-axis magnetometer (LSM303DLHC from STMicroelectronics, Switzerland) that is also commonly used in many commercial smart wearable devices. In addition, the hardware and software of the device is dedicated to research purposes, which allows the focus to be put on data collection and synchronization rather than programming another app or framework. In this study, to mimic the uncertainties that contribute to the time offsets in the real-world, a random time delay is embedded in the activation process of the Shimmer sensors.

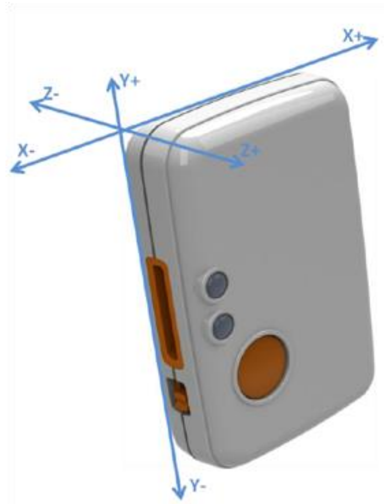

Figure 1. Shimmer3 kinematic sensors
(Image is from the company's website)

Four Shimmer units were used in this study. The units communicated with a PC via Bluetooth to transfer the measured data. The PC first reads all four data files from the current run, and uses that data to create two arrays for each Shimmer: one with all of the Unix timestamps that the PC recorded and one with all that Shimmer's local timestamps that are paired with a Unix timestamp. For the time synchronization in post-processing, the time offset between the reference Shimmer and the other three were calculated for each timestamp. This is done by subtracting the difference in the Shimmer's local timestamps from the difference in the Unix timestamps. For example, Eq. 1 can be used to calculate the offset (OT_i) between the reference Shimmer r and Shimmer i, where u represents Unix timestamp, and t represents the local timestamp:

$$OT_i = (u_i - u_r) - (t_i - t_r) \tag{1}$$

After the data collection, average of the time offsets for all sensors at each timestamp was used as the estimated time offset and added to each Shimmer's timestamps (except for the reference) for time synchronization using Eq. 2.

$$t_{i-syn} = t_i - \frac{1}{n-1}\sum_{i}^{n-1} OT_i \tag{2}$$

where t_{i-syn} is the synchronized time of Shimmer i, t_i is the measured local time of Shimmer i, and OT_i is the time offset at the i^{th} Shimmer sensor.

Experimental Verification

After the students came up with the proposed time synchronization method, experimental tests were conducted on a single-degree-of-freedom (SDOF) structure to evaluate its performance. The students were given the tasks to connect the SDOF to the shake table (earthquake simulator), investigate ways to attach Shimmers to the structure, set up data acquisition system and connecting the wires between different components. The experimental setup is shown in Figure 2. Two Shimmers and two PCB high-fidelity accelerometers (Model: 377C20) were placed on the top of the SDOF and the top stage of the shake table to measure the input acceleration of the ground and the response of the structure, respectively. A Data Physics SignalCalc Quattro Dynamic Signal Analyzer (DP240) with 4 input measurement channels (24 Bits) was utilized to record the data from the PCB high-fidelity sensors. The test matrix is shown in Table 1. Collecting data from both the Shimmers and high-fidelity sensors allows the comparison of the results to determine the reliability and accuracy of the Shimmer sensors.

Table 1. Experimental Test Matrix

Test	Description	Frequency
Free Vibration	4 in initial displacement at top	N/A
Sine Wave	Sinusoidal excitation	1 Hz / 3.9 Hz / 10 Hz
Sine Sweep	Sine waves with varying frequencies	0 – 10 Hz
Earthquake	Historical earthquake records (Kobe, Japan, 1995; Northridge, CA, 1994)	Varies

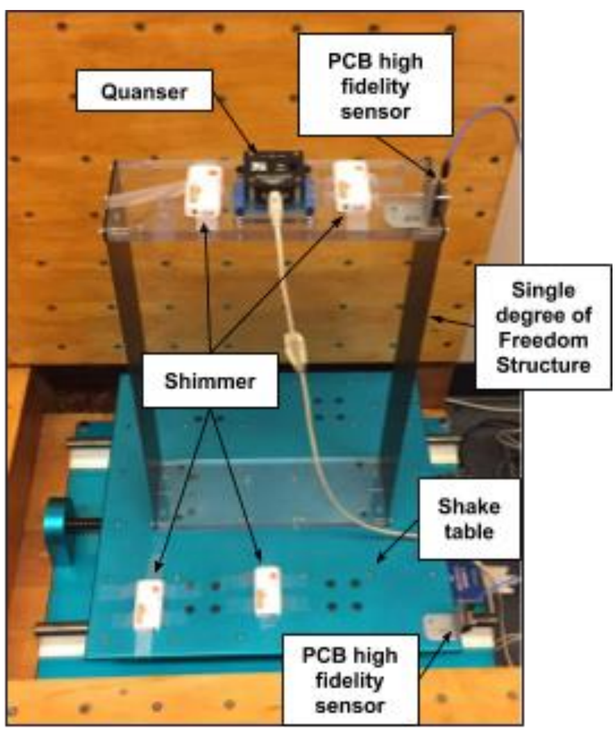

Figure 2. Experimental Setup

Research Outcomes

To first evaluate the reliability of the sensors used in smart wearable devices, the data measured from Shimmers are compared to those obtained from the high-fidelity sensors. Figure 3 shows the comparison of the acceleration response data collected from the Shimmer and the PCB high-fidelity sensor at the top of the structure in a free vibration test.

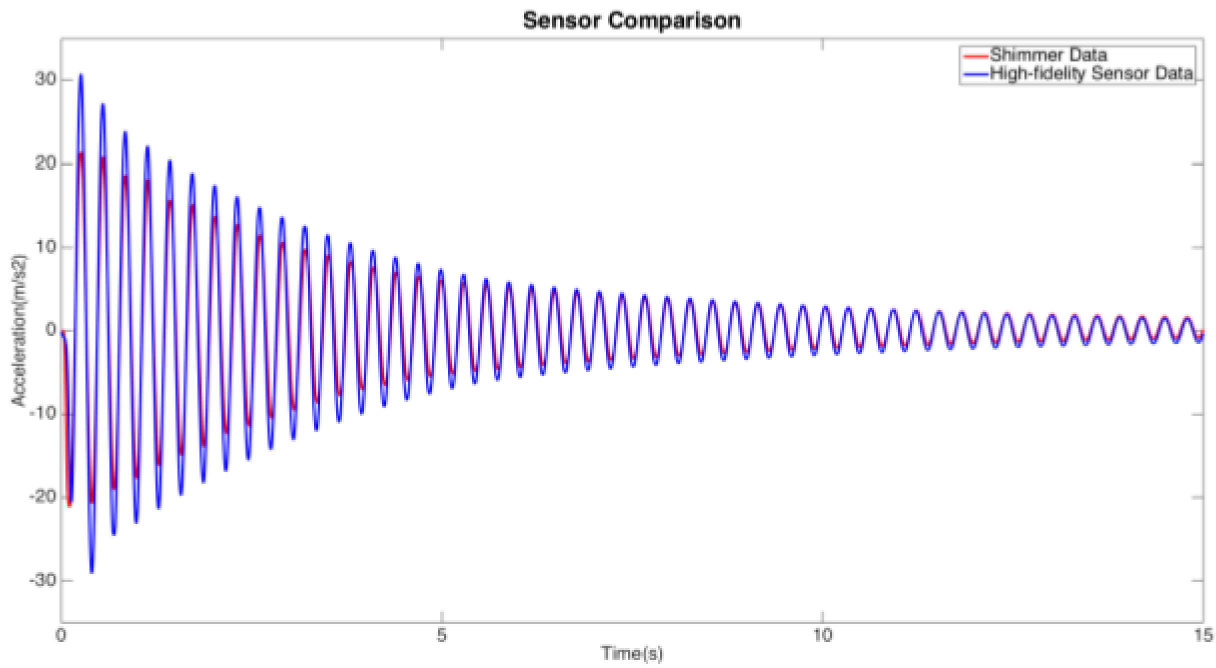

Figure 3. Comparison between Shimmer and High-Fidelity Sensor (Free Vibration)

As can been seen in Figure 3, the data gathered by the Shimmer sensor and high-fidelity sensor matches well, thus verifying the reliability of the sensors in smart wearable devices and the feasibility of using such devices for seismic measurements. Noted that the amplitudes in the comparison are slightly off, which also indicates the potential limitation of the smart wearable devices as sensors. This will be further investigated in the future study. In order to perform the reliability comparison, the data obtained from the Shimmer and the high-fidelity sensor are manually synchronized.

Figures 4-5 display the test results for a free vibration test for both the unsynchronized data and synchronized data as typical examples to demonstrate the effectiveness of the proposed synchronization method. The x-axes represent time in seconds and the y-axes represent acceleration in m/s^2. The blue and purple lines refer to the accelerometer data collected from the two Shimmers attached on top of the SDOF structure and the orange and green lines refer to the accelerometer data collected from the two Shimmers fixed on the shake table.

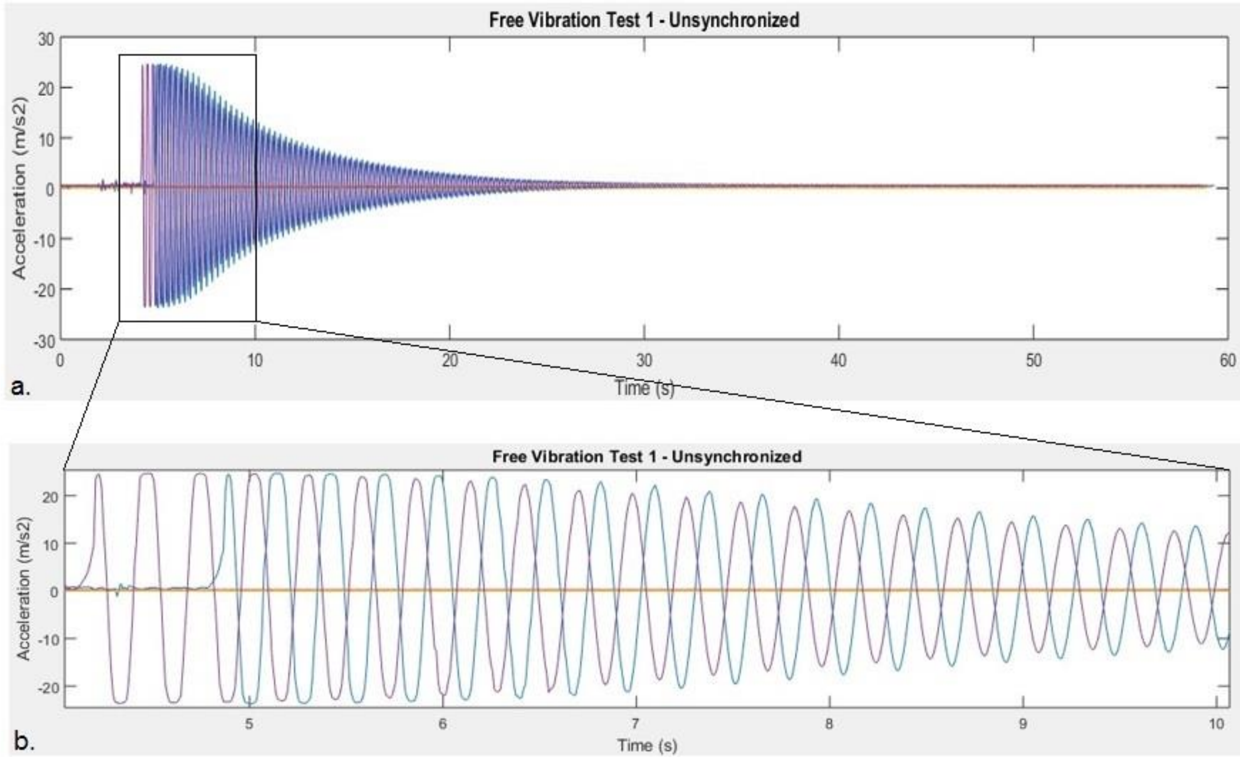

Figure 4. Unsynchronized Data – Free Vibration Test
(a) Time History Data; (b) Zoom-in Plot

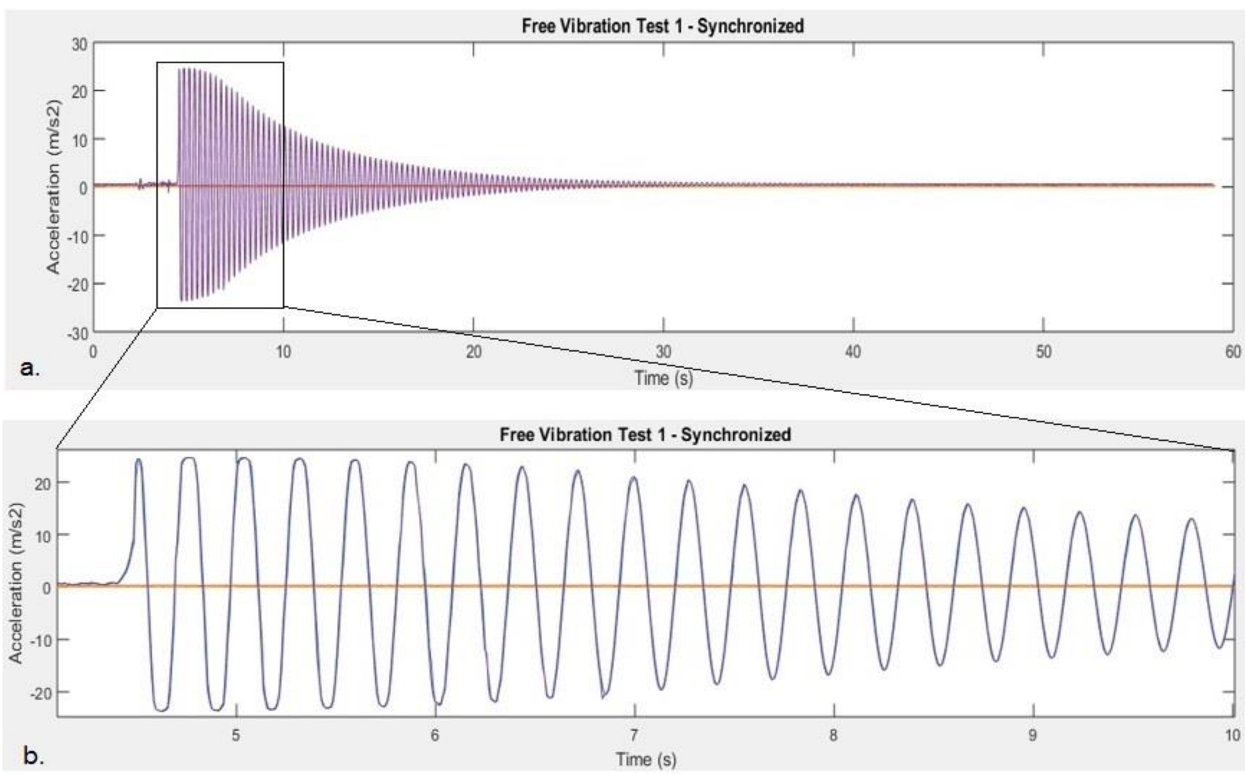

Figure 5. Synchronized Data – Free Vibration Test
(a) Time History Data; (b) Zoom-in Plot

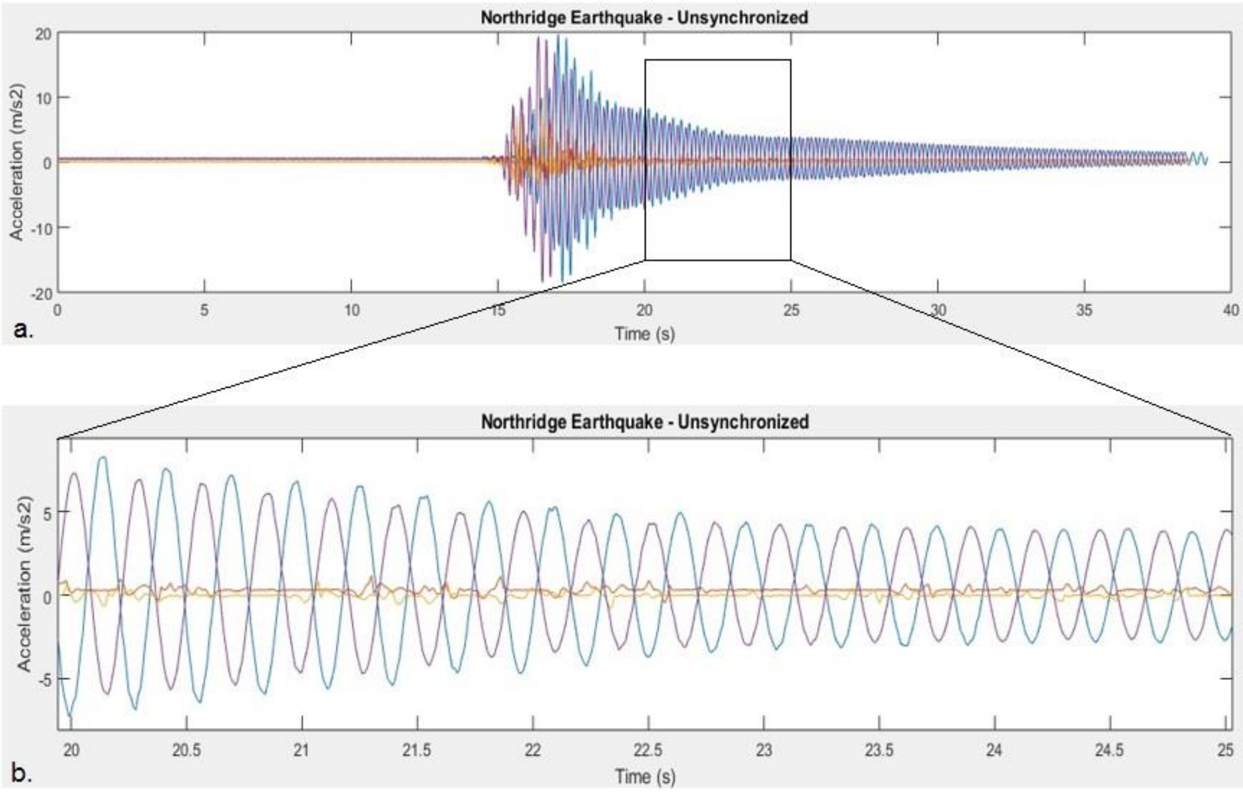

Figure 6. Unsynchronized Data – Historical Earthquake (Northridge) Test
(a) Time History Data; (b) Zoom-in Plot

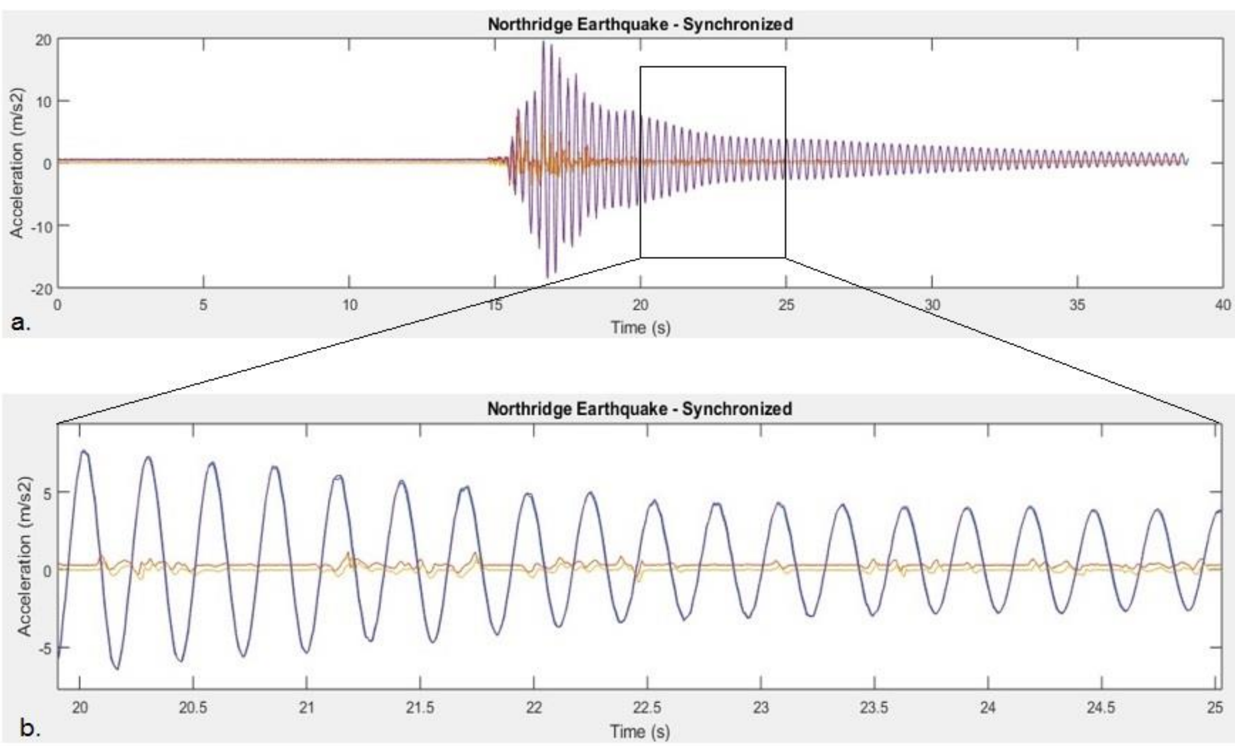

Figure 7. Synchronized Data – Historical Earthquake (Northridge) Test
(a) Time History Data; (b) Zoom-in Plot

Figure 4 shows that the two measured accelerometer data from the top two Shimmers are not aligned, proving that there is a clear offset in the timestamps. It is demonstrated more clearly in the zoom-in plot in Figure 4b. From the data analysis, the two measurements are 670.5 ms apart. The post-processing of the data was conducted in MATLAB. The data in Figure 5 is the data that has been processed by the proposed time synchronization procedure. After the synchronization, a 2 ms difference is observed between the two sensor measurements, which clearly demonstrates the effectiveness of the proposed method. Figures 6-7 show the test results of the structural responses on a 4.0 earthquake that occurred in Northridge, CA. As similar to the free vibration test, there is a large offset observed in the unsynchronized measurements. The offsets are reduced dramatically as can be seen in the synchronized data in Figure 7.

To quantify the effectiveness, the unsynchronized and synchronized offsets for all the tests are documented in Table 2. The table of numerical offsets includes values (in ms) that were calculated from the peaks of the graphs. Peaks were analyzed with special attention given to the beginning of the data sets to ensure that the correct peaks were chosen.

Table 2. Results Comparison for Unsynchronized and Synchronized Data

Test	Unsynced Offsets (ms)	Synced Offsets (ms)	Offsets Reduction (%)
Free Vibration #1	670.5	2.0	99.7
Free Vibration #2	730.0	9.0	98.8
Free Vibration #3	691.0	22.5	96.7
Sine Wave #1	690.5	5.5	99.2
Sine Wave #2	746.0	15.5	97.9
Sine Wave #3	625.0	19.0	97.0
Sine Sweep	660.0	16.0	97.6
Northridge EQ	690.0	1.9	99.7
Kobe EQ	655.0	5.7	99.1
Maximum	746.0	19.0	99.7
Minimum	625.0	1.9	96.7
Average	677.8	10.6	98.4

The results in Table 2 further confirm the effectiveness of the proposed time synchronization procedure. Before synchronization, the time offsets between each Shimmer are on average 677.8 ms with a minimum offset of 625 ms. After synchronization, the average time offset is 10.6 ms with a minimum offset of 1.9 ms. The percent decrease in offset contributed by the proposed synchronization procedure is on average 98.4%. It also can be seen from Table 2 that offsets between different Shimmers are not a constant which reflects the intended random time delay at starting the sensors.

Strategies for Student Success and Project Assessment

There were five research groups in the internship program, each consisting of one full-time student intern and three part-time student interns that were supervised by one SFSU graduate student and mentored by an engineering faculty. For this Civil Engineering group, several supplemental strategies were implemented to help students succeed in the program in addition to those offered by the program. First, group orientation meeting was held in the first day of the internship program to discuss the research direction and expected outcomes. Participating students in the internship program should ideally have completed statics, dynamics, and MATLAB. Since MATLAB is one of the essential tools needed for this particular research project, all the interns were required to participate in an intense MATLAB training at the beginning of the program. To account for the nature that students joined with different knowledge levels, bi-weekly project-specific seminars were prepared by the faculty advisor and delivered by the graduate mentor to help students acquire necessary knowledge for the upcoming research activities. Additionally, a series of training, namely Research Process, Literature Review and Conducting Research, Learning to Give Powerful Oral and Poster Presentations, and The Elevator Pitch: Advocating for Your Good Ideas were provided to help students develop independent research ability, better present research outcomes, and effectively promote research findings. Participants were divided into two groups and the team members in each group were rotated after 4 weeks of the program to promote team work and peer learning. Weekly meeting was utilized to ensure the research to be in the right direction and allow students to practice their presentation skills through the mandatory presentation given by the participating students.

In order to evaluate the success of the internship program, pre- and post-program surveys were conducted. The pre-program survey was administered on the first day of the internship program and the post-program survey was administered immediately after the students' final student presentations at the end of the internship program. The interns were asked about their purpose of participating in the internship and their perception of skills and knowledge before and after the internship program. The responses were given in a Likert scale where "1" for "strongly disagree" and "5" for "strongly agree". Results are shown in Table 3 and 4. Items with observed differences that are statistically significant are denoted with "*".

Table 3. Purpose of Internship

Prompt	**Average Response**		
	Pre	**Post**	**Change**
Gain hands-on experience in research	4.75	4.46	-0.29
Clarify whether graduate school would be a good choice for me	4.00	4.04	0.04
Clarify whether I wanted to pursue a STEM research career	3.79	4.36	0.57*
Work more closely with a particular faculty member	3.86	3.96	0.10
Get good letters of recommendation	4.32	4.25	-0.07
Have a good intellectual challenge	4.64	4.54	-0.10

* The change is statistically significant at $p < 0.050$.

Table 4. Student Perception of Skills and Knowledge for Academic and Research Success.

Question: Please indicate your level of agreement with the following statements.	**Average Response**		
	Pre	**Post**	**Change**
I am confident I will transfer to a four-year institution.	4.79	4.89	0.10
I am confident I will complete a BS in a STEM field.	4.71	4.89	0.18
I can imagine myself continuing after my BS to pursue a Master's Degree in a STEM field.	4.29	4.29	0.00

I have a clear career path.	3.79	4.14	0.35
I have skill in interpreting results.	3.86	4.32	0.46*
I have tolerance for obstacles faced in the research process.	4.04	4.39	0.35*
I am ready for more demanding research.	3.82	4.14	0.32
I understand how knowledge is constructed.	3.86	4.21	0.35
I understand the research process in my field.	3.21	3.86	0.65*
I have the ability to integrate theory and practice.	3.61	4.07	0.46*
I understand how scientists work on real problems.	3.61	4.28	0.67**
I understand that scientific assertions require supporting evidence.	4.25	4.43	0.18
I have the ability to analyze data and other information.	3.96	4.39	0.43*
I understand science.	3.71	4.00	0.29
I have learned about ethical conduct in my field.	4.18	4.07	-0.11
I have learned laboratory techniques.	3.82	3.93	0.11
I have an ability to read and understand primary literature.	3.82	4.07	0.25
I have skill in how to give an effective oral presentation.	3.79	4.29	0.50*
I have skill in science writing.	3.43	3.89	0.46*
I have self-confidence.	4.29	4.21	-0.08
I understand how scientists think.	3.71	3.89	0.18
I have the ability to work independently.	4.25	4.25	0.00
I am part of a learning community.	4.46	4.50	0.04
I have a clear understanding of the career opportunities in science.	4.18	4.43	0.25

*The change is statistically significant at $p < 0.050$.
** The change is statistically significant at $p < 0.001$.

Conclusion

The ASPIRES Summer Internship program has been successful in providing unique research opportunities for students, epically those from underrepresented minority groups. There were five research groups in the internship program. Each research group has specific ongoing research project related to the faculty advisor. In this Civil Engineering group, students evaluated the reliability and accuracy of using the wearable device as seismic sensors and provided a viable solution to the time synchronization challenge for that purpose. Systematic workshops and training were provided to help students succeed and ensure meaningful research experience. Weekly meeting with mandatory presentation was utilized to guide the students along the right path while providing them enough freedom to explore new ideas. Hands-on experiments were conducted to allow students to consolidate the gained knowledge and verify the proposed solutions. As can be seen from Table 3 and 4, participating students demonstrated improvement in understanding research process, analyzing data, interpreting results, and integrating theory into practice, as well as increase in tolerance for obstacles and ability for oral presentation and academic writing. The program shows that even students with little or no background in engineering courses or research topics were able to succeed in the program and experience the excitement of research.

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