Advancement of a Lie Detector Algorithm

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Abstract

The traditional lie detector device included components such as heart rate sensors, electrodermal activity sensors, pneumographs, and movement sensors. After being provided with an Excel spreadsheet of sample polygraph data that used these five sensors, data analysis was conducted on Microsoft Excel, and an algorithm was computed that revealed an 80 percent accuracy of both the original device and algorithm. The algorithm involved comparing the averages from each sensor with a percent difference formula to determine if deception was occurring. The original algorithm concluded that questions 1, 4, 5, 7, 9, and 10 were possible lies. The average cost for the original polygraph device was found to be approximately 1,225 dollars. With the goal of improving accuracy, the addition of two other sensors, a temperature sensor and a blood pressure cuff was suggested. Analysis of the movement data suggested unreliability due to the voluntary nature of movement, therefore, the movement sensor was removed. The improved algorithm concluded that questions 1, 5, 7, 9, and 10 were possible lies. This improved device had a 90 percent accuracy and a proposed cost of 1,199 dollars, including the technician fee. The suggested improvements would provide a 10 percent increase in accuracy, and a 20 percent decrease in cost for the device. Suggestions to provide a more reliable polygraph test included determining a more accurate baseline using more known truths, controlling the external environment, having an accurate mental and physical health background check, and potentially even using alternatives such as brain imaging or voice stress analysis.

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1 Introduction

Data from a lie detector was provided that included values from the upper pneumograph, lower pneumograph, movement, cardio, and EDA sensors from a particular test subject. This data was used to create an algorithm to determine whether the test subject was lying or not. By creating an algorithm, the data was translated to accurately determine if deception was occurring.

Initially, information was gathered on the history of the polygraph machine, previous and current research, reliability and effectiveness of the device, and alternatives to the lie detector. This background research provided adequate information on the polygraph test in order to better understand the given data. This data was then analyzed and compared to the control. Following the data analysis, potential improvements to the sensor package were evaluated along with determining the cost-effectiveness of the new design. The underlying need met was to analyze whether or not deception was occurring while questioning the subject. This research also proposed advancements to the polygraph machine that would help increase the reliability of results and effectiveness of the test in general, especially while keeping the cost at a reasonable price.

1.1 Problem Statement

The goal of the project was to create a reliable algorithm or logical method which would accurately determine whether a subject was lying or not based on certain parameters given from a previous lie detector test. In order to do so, the data had to be effectively analyzed and interpreted. The major problems of the project not only included executing effective data analysis, but also evaluating possible improvements that would increase the reliability of a lie detector test. Overarching issues included suggesting improvements to the device or algorithm and analyzing the cost of the lie detector as well.

There were several major objectives there were accomplished by conducting this research. The first objective was to conduct sufficient background research to better understand the reliability and effectiveness of the lie detector test. The next objective was to develop an algorithm that would determine if deception was occurring or not by analyzing the given physiological responses of a particular test subject. The third objective was to evaluate potential sensor improvements based on the accuracy of the developed algorithm to further enhance reliability. Lastly, the cost analysis of the improved device also had to be determined.

1.2 Background Research

1.2.1 The Polygraph Algorithm

Polygraphs, informally known as lie detector tests, cannot explicitly detect lying due to the complex nature of the human body and its processes, however, they can infer lying through the results of specific physiological measurements recorded during the test. Before modern day lie detectors were created, primitive methods such as the excretion of saliva, paleness of one's face, racing of one's pulse, and the trembling of one's hand were used to detect lies (Volyk). As time progressed, more emphasis was placed on scientific methods until the invention of the modern-day polygraph by John Larson in 1921 ("The Truth About Lie Detectors"). The measurements in a polygraph typically included blood pressure, heart rate, breath rate and depth, movement, and skin conductivity, measured by the appropriate sensors.

When a polygraph test was conducted, the subject was attached to the available sensors and asked a series of control questions to set their baseline readings ("The Truth About Lie

Detectors”). The subject was then asked a series of relevant questions while their physiological responses were recorded with the sensors. At the conclusion of the polygraph test, data was collected and scored by one of the following: graph analysis, manual numerical analysis, or a computerized algorithm (Haider et al. 73). Using the initial baseline for each set of data, as well as markers for when each question was asked and answered, the responses were deemed “truthful” if they matched the baseline, and “deceptive” if they deviated significantly (Olsen 349). Ultimately, the polygraph test compared the subject’s physiological response between questions to determine if the subject’s response was truthful or not.

1.2.2 Effectiveness of the Polygraph Test

Although popularized by media and society, polygraphs cannot accurately test for whether a subject lied or not. They instead tested for “deceptive reactions” (“What Is A Polygraph”). They were used with the preconception that people would not lie or deceive without showing nervousness or some type of anxiety, which came from the idea that people were afraid of the repercussions that came from lying. However, people who had lower anxiety levels would be able to “trick” a lie detector. Serial killers in the past as well as other prolific criminals have been known to cheat lie detector tests when they were admissible in court, which revealed a huge flaw in their reliability and effectiveness. Due to the inability to prove that deviations against the control from a polygraph reading were due to lying, the polygraph test was not admissible in court or legal to use by private employers following the landmark case of Frye vs. United States in 1923.

When individuals actively attempted to detect deception, their accuracy levels were barely above chance, ranging from 45 percent to 60 percent and averaging 54 percent (Synnott 63). However, The American Polygraph Association, which sets standards for testing, said that polygraphs were "highly accurate," citing an accuracy rate above 90 percent when done properly. Critics, however, claimed the tests were correct only 70 percent of the time (Vogel).

1.2.3 Previous and Current Research

In recent history, an increased emphasis was given on scientific techniques and devices to detect a liar. In 1875, Italian physiologist Angelo Mosso demonstrated that blood pressure, blood volume, and pulse frequency changed depending on changes in emotions of a subject. Based off of this finding, an Italian Physician, Cesare Lombroso, experimented with a device measuring blood pressure and pulse to detect deception in criminal suspects (Vicianova).

As the years progressed, so did the inventions for a possible lie detector. In the years leading up to World War I, Harvard psychologist Hugo Münsterberg used a variety of instruments to record and analyze subjective feelings. William Marston, after he worked in Münsterberg's lab, used Lombroso's device as an example to invent a systolic blood pressure cuff to find the link between vital signs and emotions (Lewis and Cuppari). In tests on fellow students, he reported a 96 percent success rate in detecting liars (Marsh).

Although polygraph tests were not commonly used in law enforcement in recent years, there was still research to develop an advanced lie detector with increased effectivity and reliability. In 2002, Daniel Langleben, a professor of psychiatry at the University of Pennsylvania, began using functional magnetic resonance imaging, or fMRI, to do real-time imaging of the brain while a subject was either telling the truth or lying. Langleben found that the brain was generally more active when lying and suggested that truth telling was the default modality for most humans (Ganis et al). Langleben had reported being able to correctly classify individual lies or truths 78 percent of the time. Other recently researched techniques include the use of BOLD fMRI to compare brain activation in truth, spontaneous lies, and memorized lies, as well as artificial intelligence used to assess changed in eyes, voice, posture, etc. to infer deception (Ganis et al).

More recently, researchers at the University of Arizona developed the Automated Virtual Agent for Truth Assessments in Real-Time, or AVATAR, for interrogating an individual via a video interface (Marsh). The system used AI to assess changes in the person's eyes, voice, gestures, and posture that would raise flags about possible deception. According to Fast Company and CNBC, the U.S. Department of Homeland Security had tested AVATAR at border crossings to identify people for additional screening, with a reported success rate of 60 to 75 percent (Marsh).

1.2.4 Alternatives to the Polygraph Test

Common alternatives to the polygraph test included brain scans, such as Magnetic Resonance Imaging (MRI), functional Magnetic Resonance Imaging (fMRI), and Positron Emission Tomography (PET) scans (National Research Council 158). Studies showed that brain imaging had the ability to be extremely accurate, as different parts of the human brain were used in deception while separate parts were used while honestly recounting events (National Research Council 158). While brain imaging had the potential to be extremely accurate, it cost much more than the standard polygraph and was much less accessible to investigators. Outside of brain imaging, alternatives included Certified Voice Stress Analysis, which used the tone and structure of the subject's voice to determine deception (Cino).

Less costly and technical alternatives involved the use of a trained investigator to determine whether someone's demeanor changed while they answered certain questions, which was aimed at seeing whether someone was lying. Some examples of human demeanor that were often measured by investigators were facial expression, word choice, and body movement and language (Cino). Studies showed these alternatives had varying degrees of accuracy, with brain imaging shown as the most accurate, while investigating demeanor changes was the least accurate (National Research Council 155). However, while alternatives have risen over the years, the polygraph had proved to be resilient due to its simplicity and accuracy.

2 Methods and Materials

2.1 Lie Detector Algorithm

Initially, the lie detector data was analyzed to observe trends and variations throughout the duration of the interview. Microsoft Excel 2016 was used to sort, calculate, and analyze the data. The data was first broken up into comparable time slots for each of the five different physiological sensors. A baseline was determined that showed the subject's physiological response while at rest. This baseline came from one minute of the initial data where the subject was not being questioned. This minute started exactly one minute after the sensor started recording and ended sixty seconds later. This segment of time, called the pre-question period, was used to measure of how the subject's body responded under normal conditions. This also indicated the average variation expected from the subject's physical responses because it was from a larger period of time, which allowed the subject's body to react as it normally would. The ten questions were then split up into different time periods to compare the subject's response between questions. Each question and response were given their own combined time period, with the pre-question period used as a baseline for comparison.

Based on previous research, it was determined that when the subject had a physiological response to the question, their reaction would often start before the subject even started their response. Hence, data was grouped from the beginning of the question being asked by the examiner to the end of the subject's response. Therefore, the analysis for each question started at the beginning of the investigator asking the question, which was shown as Q1 start, and continued until the end of the subject's response, shown as R1 end in the given Microsoft Excel data. Cardio, upper pneumograph, lower pneumograph, electrodermal response, and movement data were all analyzed to determine deception compared to the pre-question period. For example, if a subject was nervous and started sweating, the electrodermal sensor, as shown in figure 1, would detect an increased voltage due to the increased sweat production.

Figure 1. An electrodermal sensor placed around a subject's arm (Movisens)

Different methods of comparing and analyzing the differences between question were used to find the most effective way to determine deception. The three main functions used to analyze each of the eleven time periods were average, standard deviation, and the difference between the maximum and minimum values. After closely analyzing the data, it was found that the average changed significantly between questions, which made it easier to determine if deception was occurring. The average formula was able to obtain the most accurate and reliable results while being relatively simple to use, and it was also easily applicable to all five sensors.

Thus, the average formula, shown as Equation 1, was used to analyze the data and determine if deception was occurring.

$$\text{Average} = \left(\frac{\text{sum of data points}}{\text{total number of data points}}\right) \text{ (Equation 1)}$$

It was then determined that there would need to be a control question that was a known truth in order to compare the other questions to. For this algorithm, that known truth was Question 2, as this question simply asked the subject's name. The recorded time period for this question showed how the subject's body responded when being asked and answering a question truthfully. It was then decided to use the percent difference formula shown as Equation 2 below to determine the difference between each question from the control question.

$$\text{Percent Difference} = \frac{(|x_{control} - x_{experimental}|)}{x_{control}} \times 100 \text{ (Equation 2)}$$

In Equation 2, $x_{control}$ was the average value of the control question, which was Question 2, and $x_{experimental}$ was the average value of the question that was being compared to identify deception. A high percent difference showed that deception was more likely to be occurring while a low percent difference indicated that deception was not likely to occur. A percent difference was calculated for each individual question and response, and these percent differences were summed, as shown in Equation 3, to find the total deviation compared to the control question.

$$\text{Total difference} = (\text{Percent Difference}_{Heart\ Rate}) + (\text{Percent Difference}_{Upper\ Pneumograph}) + (\text{Percent Difference}_{Lower\ Pneumograph}) + (\text{Percent Difference}_{EDA}) + (\text{Percent Difference}_{Movement})$$

(Equation 3)

The sum of these percent differences was compared to the sum of the percent differences of the pre-question period. An If statement, shown as Equation 4, was then used to derive the final analysis.

$$\text{If}(\text{sum of percent differences}_{\text{experimental}} > \text{sum of percent differences}_{\text{control}}, \text{"Lie"}, \text{"Truth"}) \quad \text{(Equation 4)}$$

If the sum of the percent differences for a particular question was greater than the sum of the percent differences for the pre-question period, then the response to that particular question was considered a lie. If the sum of the percent differences for each question were smaller than the sum of the percent differences for the pre-question period, then the response to that question was considered a truth.

The algorithm used to determine whether or not deception was occurring during the polygraph test was summarized in Figure 2, which made a concise and simple way for the investigator to determine if deception was occurring.

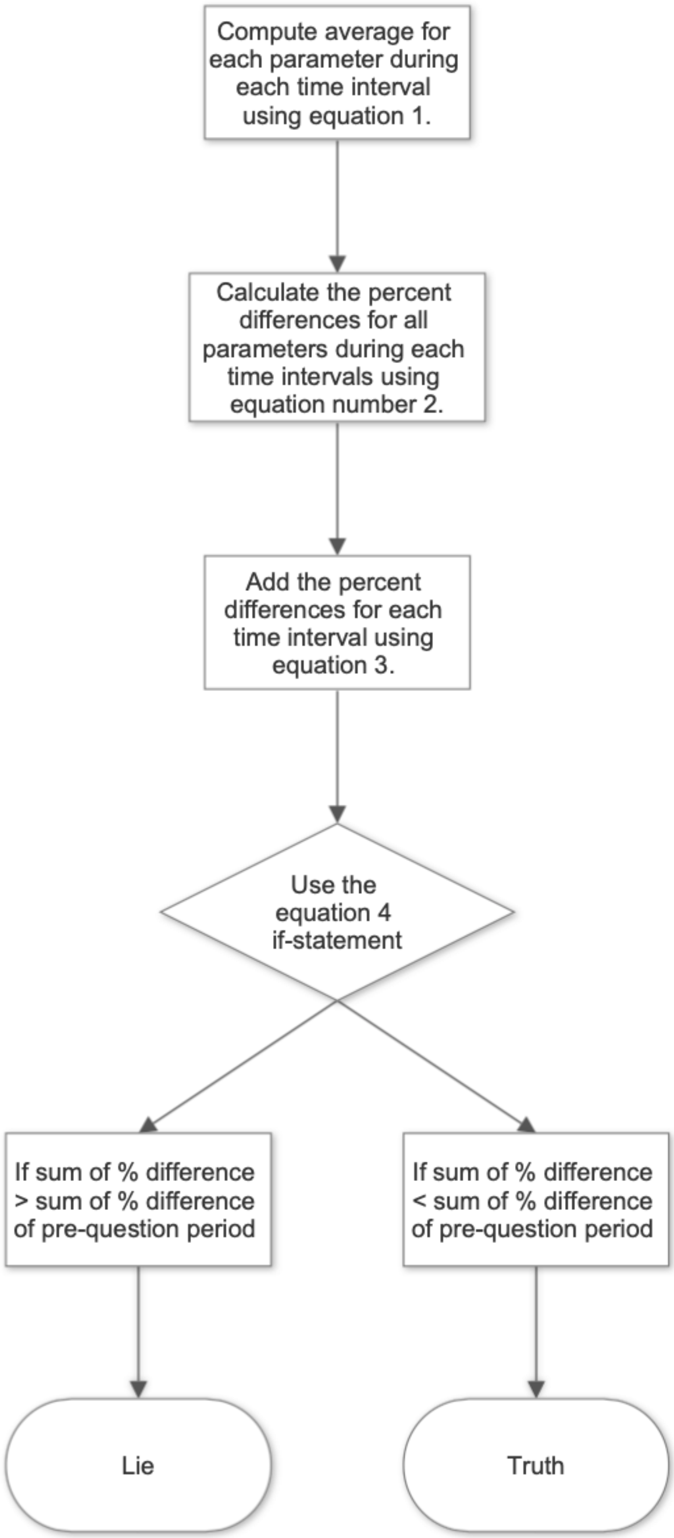

Figure 2. The algorithm portrayed as a flowchart

2.2 Improvement Evaluation

In order to analyze potential improvements to the sensor package, additional improvements were evaluated based the decision matrix shown as Table 1 below.

Table 1. The decision matrix with all of the sensors included

	Ease of Use	Effectiveness	Consistency	Total
EDA Sensor				
Cardio Sensor				
Upper Pneumograph				
Lower Pneumograph				
Movement Sensor				
Points possible	20	40	40	100

The five existing sensors were evaluated for ease of use, effectiveness, and consistency. Ease of use took into account how simple it would be to operate that particular sensor by the technician without any additional training. Values for effectiveness were computed based on how accurate those particular sensors were. The values for consistency took into account whether the sensor was measuring a voluntary or involuntary response and how that particular response would have been impacted by external factors. The scores were reasonably calculated with the unanimous consent and agreement of the primary researchers involved in this project.

Each component was scored out of a total of 100 points. If any component had a score less than 70 out of 100, which is the average accuracy of a standard lie detector, it would be removed from the improved device. Based on the decision matrix, each sensor either increased or decreased the overall percent accuracy of the machine.

Several additional sensors were looked at to improve the accuracy of the device. For example, an added blood pressure and temperature sensor were discussed to increase the physiological responses that the investigator was able to track. The company QardioArm was considered for its smart blood pressure sensor valued at 99 dollars. Similarly, Phillips skin temperature probe, valued at 150 dollars, was considered. These added sensors were evaluated using the same decision matrix shown in Table 1.

Such added improvements would give the investigator a better picture of the subject's physiological responses and help determine if deception was occurring. All improvements were analyzed with data found by their expected relationship with the other sensors. For example, the cardiac and blood pressure sensors had a directly proportional relationship, so average values were computed for the additional sensors with use of that relationship. The initial algorithm was then used to determine which sensors improved the test's accuracy to determine if they should have been incorporated into the improved model.

2.3 Cost Analysis

In order to determine the cost for a baseline model of a polygraph test, average prices of multiple baseline models were taken. The company Lie Detector Inc. was contacted to find an average price of their device. The model selected for this project was Lie Detector Inc's Polygraph Expert +, valued at 999 dollars. This included a standard polygraph machine along with sensors capable of monitoring EDA, breathing rate, blood volume pulse, heart rate variability, blood pressure and temperature. The price point of the Polygraph Expert + was used as the average price of a standard polygraph test and was modified to adjust for the sensors given by the client. The cost of a technician making improvements and operating the polygraph also had to be factored into the final cost. The price of the temperature and blood pressure sensors had to be taken out of the average cost because the polygraph data that was analyzed did not include either of those sensors. The cost of the added movement sensor, produced by the company Lafayette Instruments and valued at 475 dollars., also had to be factored in to better reflect the lie detector data initially analyzed. The average cost of a baseline model can be calculated by using Equation 5 below.

$$\text{Cost}_{\text{base model}} = (\text{cost}_{\text{device}} + (\text{cost}_{\text{movement sensor}})) - (\text{cost}_{\text{blood pressure sensor}} + \text{cost}_{\text{temperature sensor}}) \quad \text{(Equation 5)}$$

The base model cost was used to analyze the cost of the improved sensor. In order to reflect the improvements made to the sensor, the removed sensors had to be factored out of the base model cost. Furthermore, the cost of any added sensors had to be factored in to determine the updated overall cost of the polygraph. The cost of the improved sensor was calculated by using Equation 6.

$$\text{cost}_{\text{new model}} = (\text{cost}_{\text{base model}} - \text{cost}_{\text{removed sensors}}) + \text{cost}_{\text{added sensors}} + (\text{cost}_{\text{technician}} \times \text{hours worked})) \quad \text{(Equation 6)}$$

3 Results

3.1 Lie Detector Algorithm Results

Using the methods outlined previously, the data was analyzed to determine whether or not deception was occurring. The percent difference for each sensor was calculated in comparison to Question 2 and is shown in Table 2 below.

Table 2. Results using the percent difference formula

Question	Sum of Percent Differences
Pre-question period	11.3219999
1	20.7862687
2	0
3	6.81888639
4	13.9846669
5	13.4885145
6	9.49997081
7	7.4297842
8	11.569763
9	23.2917506
10	20.4703578

The sum of the percent differences for each question were than compared to the percent difference from the pre-question period using the “if” statement. The results of this assessment, shown in Table 3 below, determined whether the subject was most likely practicing deception or telling the truth.

Table 3. Results of the initial lie detector algorithm

Question	Result
Pre-question period	Truth
1	Lie
2	Truth
3	Truth

4	Lie
5	Lie
6	Truth
7	Lie
8	Truth
9	Lie
10	Lie

Using the initial algorithm, questions 1, 4, 5, 7, and 9, and 10 were probable deceptions, while questions 2, 3, 6, and 8 were assumed to be truths. This presented an accuracy of 80 percent for the current algorithm.

3.2 Improvement Evaluation

The decision matrix was filled in to determine which sensors were the most reliable overall and which sensors should have been removed in the improved model. The completed decision matrix for all five sensors and their scores out of 100 possible points was shown in Table 4.

Table 4. The completed decision matrix for all five sensors

	Ease of Use	Effectiveness	Consistency	Total
EDA Sensor	16	34	22	72
Lower pneumograph	14	37	28	79
Upper Pneumograph	14	37	28	79
Movement Sensor	8	17	3	30
Cardiac Sensor	12	39	37	88
Points possible	20	40	40	100

The completed decision matrix identified the cardiac sensor, the upper pneumograph, and the lower pneumograph to be the best sensors with a score of 88, 79, and 79 respectively. Due to the movement sensor's low score, it was decided that this sensor would be removed from the improved model.

After analyzing scores for each sensor, it was decided that the temperature sensor and blood pressure sensor should be incorporated into the improved model. The values for both temperature and blood pressure were computed using the relationship these involuntary bodily responses had with heart rate.

Table 5. The completed decision matrix for the added sensors

	Ease of Use	Effectiveness	Consistency	Total
Temperature Sensor	18	30	35	83
Blood Pressure Monitor	16	33	36	85
Points possible	20	40	40	100

As seen below, the sum of percent difference of all the six sensors, after removing movement and adding temperature and blood pressure instead, gave the following values as seen in Table 6 below.

Table 6. The sum of the percent differences for the improved model

and the results of the lie detector test

Question	**Sum of the Percent Differences**	**"If" Statement Result**
Pre-question period	6.59463541	Truth
1	23.3827853	Lie

2	0	Truth
3	4.29720794	Truth
4	6.17336092	Truth
5	8.30035863	Lie
6	5.90573679	Truth
7	17.713738	Lie
8	6.54276211	Truth
9	28.2074127	Lie
10	25.4731056	Lie

Additionally, after adding reasonable values for both temperature and blood pressure, the updated results for the lie detector showed that questions 1, 5, 7, 9, and 10 were lies. Questions 2, 3, 4, 6, and 8 were concluded as truths. The accuracy of the device significantly increased, going up from 80 percent to almost 90 percent accuracy when compared to the final results provided.

3.3 Cost Analysis

The base model cost was calculated by plugging the values for the different components into equation 5. The calculated cost for the base model was 1,225 dollars. This cost was then used to calculate the improved sensor cost by removing the move sensor and factoring in the blood pressure cuff and temperature sensor cost. The cost of the technician who installed the added sensors was determined to be 100 dollars per hour. By adding two additional sensors and analyzing the algorithm, it was determined that it would take the technician two hours. The calculation for the improved sensor cost was computed by plugging in the respective values into Equation 6. The cost of the improved model of the lie detector, with the technician fee, was 1,199 dollars. The cost of the improved detector device, without the technician fee factored in, was 999 dollars, significantly less than the initial cost of the device.

4 Discussion

4.1 Lie Detector Algorithm

The lie detector algorithm used gave a reliable and easy way to calculate whether or not deception was occurring using a standard polygraph test. The benefits of using this algorithm far outweighed the disadvantages because the algorithm was cheap to run and easy to use. The algorithm relied on percent differences, and this was calculated using knowledge of basic Excel equations. It was fast and easy for the technologist to run. This algorithm also had the advantage of being a reliable way to tell whether or not someone is lying. If the average response of the subject's heart rate, movement rate, electrodermal response, and upper and lower pneumograph results were significantly different than the chosen control question, then it was assumed that the subject had this increased physiological response because the subject was lying. This meant that if the subject's physiological responses were significantly higher during the said question and response, shown by a higher average for a certain sensor, deception was more likely occurring. If the physiological responses were the same or less than the pre-question period, shown by a lower average for a certain sensor, it was more likely to be a truth. This algorithm was based on the notion that any physiological response associated with the question or response would lead to a greater average voltage seen during that particular time period. For example, under stress, the human heart would beat faster and harder, causing the average voltage for the cardio sensor to be higher if the subject was under stress. Using this algorithm allowed the investigator to not only assess if there was an increase in the subject's physiological response, but also to see if the response if significant enough to warrant the response being seen as deception. This algorithm had the advantage of determining the normal amount of variation expected by the subject and then comparing each question's physical response to the normal amount of variation expected.

While this algorithm had many benefits, there were several negative factors that were associated with the lie detector test since lie detector tests had the ability to be easily swayed in either direction. The data that came from the EDA and movement sensors had an extremely high variability, making it harder to analyze. Furthermore, it was found that the movement data had outliers that could affect the outcome of the algorithm. While the differences between the averages showed increasing or decreasing intensities for each reaction, it would have been easily swayed if the subject were to have an unrelated physical ailment, such as a sneeze or cough. Furthermore, some of the individual sensors could have been analyzed more effectively in a different way. For example, the movement data would have been more effectively and reliably evaluated using the standard deviation values, but since this method could not be used consistently across all five sensors, the average was used as a way to highlight changes in physiological responses throughout every sensor. While every polygraph machine had the potential to give a false positive or negative, the algorithm stated was a reliable and effective method to analyze the responses of any given subject.

4.2 Improvement Evaluation

After computing the initial algorithm and determining its accuracy, it was determined that there were several other parameters that could be measured. Temperature and blood pressure measurements were two of these potential parameters considered that could be added to detect even the slightest changes that would indicate fear and stress, increasing the overall accuracy of the test.

Additionally, the external environment had the potential to alter the behavior and physiological responses of the subject. Many factors such as the setting, current mental and physical health of the subject, attitude of the examiner, and the reason for conducting the polygraph test could have significantly influenced the results. Therefore, a room temperature that was best preferred by the subject should have been used. This would have automatically eliminated the influence of external factors on the test such as sweating or shivering, which would have otherwise negatively impacted the results of the EDA and movement sensors respectively. For these reasons, the movement sensor was removed because it was more prone to the subject's response not being correlated to their actual anxiety levels.

The most important factor that was taken into account when deciding between the sensors was whether the sensor measured a voluntary response or an involuntary response. In the initial lie detector device, movement was the only voluntary response measured. The remaining four sensors all measured involuntary body responses. This raised concerns regarding the reliability of the movement sensor since it could have altered the results of the entire test due to potential outliers in the data sets, as observed during the time intervals for questions 4 and 5 in the initial lie detector algorithm. Therefore, both temperature and blood pressure sensors were added since they could not have been intentionally altered by the subject.

The improved sensors increased the accuracy of the algorithm by reducing the chance of outliers and error. By getting rid of the movement sensor, only involuntary physiological sensors were used in the improved device, meaning that the subject had no direct control over the physiological responses. The addition of the QardioArm blood pressure cuff and Phillips temperature sensor increased the accuracy of the overall algorithm and decreased the chance of the algorithm resulting in a false negative or false positive.

4.3 Cost Analysis

The cost for the movement, temperature, and blood pressure sensors was calculated because these sensors were either added or removed to the base model. A technician was paid 100 dollars an hour to operate the polygraph machine. Polygraph tests, on average, lasted about two hours total, so the cost of paying the technician to conduct the test was 200 dollars, which was also factored into the final cost of both the base and improved model.

The cost of the base model was less than the cost of the improved model. There were many benefits that came with the improved model. The improved lie detector's cost was almost a 20 percent decrease from the cost of the baseline model. Additionally, with the added temperature and blood pressure sensors, the accuracy of the lie detector went from 80 percent to 90 percent. The removal of the movement sensor not only decreased the cost but losing it did not impact the overall accuracy negatively. The added sensors were superior to the base model sensors since products from reliable companies were being used, not compromising on the quality of the product. Overall, the cost of the improved lie detector proved to be superior compared to the baseline model without having any negative impacts.

The high reliability of lie detectors was very beneficial to public health, safety, and welfare since, if scientifically proven to accurately detect deception, suspected criminals and serial killers could be easily incarcerated if proven guilty through a lie detector test. Therefore, the lie detectors could significantly improve the justice system and employment hiring processes globally and within specific cultures. Accuracy and affordability of the device would even discourage social evils like lying and cheating, primarily due to the fear of being caught by a lie detector. For this reason, it was pivotal for the polygraph test to be economical and widely accessible, even producing potentially disposable tests. While production of the components to produce the device would harm the environment, safe disposal methods should be used. Additionally, graphs should be illustrated on the computer rather than paper so the device would be eco-friendlier.

5 Conclusion

Traditional lie detectors included features such as heart rate sensors, electrodermal activity sensors, pneumographs, and movement sensors. The initial analysis of the Excel data used the second question as the control for the full data analysis. This analysis, which used averages, percent differences, and if-statements on an Excel spreadsheet, showed seventy percent accuracy on the original lie detector algorithm. A formula was devised to calculate a total cost of 1,465 dollars for the device with and without proposed improvements to the sensors.

Although this algorithm was cheap and easy to use, it was determined that the participant could sway the test by having a voluntary response, therefore swaying the results. The improvements suggested to be made to the original device include the addition of a temperature sensor and a blood pressure cuff, and the removal of the movement sensor. However, these improvements must be used in environments that have controllable factors such as specific room temperature, calm room setting, and accurate baselines.

The improved sensor was made by taking getting rid of the movement sensor and adding a blood pressure and temperature sensor to improve accuracy. To determine the cost of the proposed improvements to the original lie detector device, the average price of each sensor was found. After factoring in the cost of the new sensor, factoring out the cost of the temperature sensor, and adding the average cost of a technician, the cost for the improved base model lie detector came out to be 1,199 dollars. This model shows an approximately 20 percent decrease in cost, and a 10 percent increase in accuracy. According to these percentages, the improved lie detector device should prove superior to the original model.

5.1 Future Work

Several additional changes to be made to increase the reliability of the polygraph and provide a more accurate result. The polygraph test itself could be made more reliable by asking more "known truths" to establish a more accurate baseline. Questions such as the subject's name, birthdate, and marital status would have an answer known to the investigator, so it would better show how the subject's body reacted while telling the truth and would give the investigator more of a control to compare each question to. Similarly, variations in physiological responses could be compared to not only one, but two different periods to determine the normal variation expected of the subject.

A more accurate baseline could also be determined by lowering the anxiety of the subject. Future studies should, therefore, focus on conducting anxiety-relieving activities like deep breathing or yoga before commencing the examination. The results of these polygraph tests should then be compared to tests without any prior anxiety-relieving activity to determine whether lowering anxiety makes the test more accurate by having a more accurate baseline. More research should also be done using some of the alternatives to the polygraph machine, such as brain imaging and voice stress analysis.

When using the polygraph machine on a group of subjects, blind testing and randomized experimentation should have definitely been considered. Standardization of all procedures with adequate sample sizes must also be ensured to allow for visible trends in data sets. Additionally, there should also have been a few experimental controls to allow for reasonable comparison between tests. While keeping all of those factors in mind to produce statistically significant results, the device itself should be constantly improved and the cost kept at a reasonable level.

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7 Appendices

The raw averages (voltage)

question	Up pneumo	Lo pneumo	EDA	move	HR
pre-question	4.036200717	1.235304793	3.50993734	1.83891878	82.1428571
1	3.877660742	1.081951738	3.5129251	1.82378711	82.9787234
2	4.029352279	1.21981154	3.55169003	1.7600538	82.4175824
3	4.052261029	1.240638241	3.50391823	1.8044367	80
4	4.044054019	1.233195672	3.51185705	1.89753699	79.3650794
5	4.058285289	1.246112659	3.51364305	1.66873946	86.1538462
6	4.023260025	1.214280039	3.49931545	1.82331425	76.5957447
7	4.076668373	1.262813712	3.50989535	1.82801166	79.7202797
8	4.014200375	1.20604157	3.51223	1.84853172	76.5957447
9	4.142336282	1.322483593	3.5160352	1.8194467	79.3650794
10	3.665449758	1.214566727	3.50572238	1.85439174	80.5369128

The raw percent differences as compared to Q2

Question	EDA	Lower	Upper	HR
control	1.17557239	1.270134948	0.169963752	2.942694889
1	1.091450019	11.3017296	3.764663061	1.007326007
2	0	0	0	0
3	1.34504406	1.707370328	0.568546724	0.67624683
4	1.121521714	1.097229507	0.36486611	3.58974359
5	1.071235699	2.156162468	0.718056108	4.354904355
6	1.474638224	0.453471751	0.15119684	3.82642998
7	1.176754508	3.525312733	1.174285384	7.692307692
8	1.111021049	1.12886049	0.376038182	3.926842388
9	1.003883309	8.417042254	2.804023962	7.692307692
10	1.294247058	0.429969153	9.031290783	4.354904355

Data with proposed modifications

question	bpm	new average	percent difference
control	80.53691275	96.5	0.518134715

	1	82.1428571	99	3.10880829
	2	82.9787234	96	0
	3	82.4175824	96	0
	4	80	96	0
	5	79.3650794	96	0
	6	86.1538462	96	0
	7	76.5957447	98	2.07253886
	8	79.7202797	96	0
	9	76.5957447	100	4.14507772
	10	79.3650794	101	5.18134715