Vision-based Vibrator Calibration

A. Małecki, A. Selma, M. Čepec, M. Nielsen, S. Jensen

Department of Materials and Production, Aalborg University
Fibigerstraede 16, DK-9220 Aalborg East, Denmark
Email: aselma21,amalec18,mcepec18,madshn18,srje21@student.aau.dk,
Web page: http://www.mechman.mp.aau.dk/

Abstract

Vibratory feeders are commonly used in the manufacturing industry to align and feed various types of parts into machines. The primary types of feeders are circular and linear. The main parts are the feeder bowl and the drive unit. The bowl is equipped with traps that ensure the parts are all oriented in the same way. The movement of parts happens by vibrating the bowl feeder.
Since the mechanical properties of the feeders can change over time or depend on what parts are being fed, they require calibration to ensure a good and stable feeding speed and optimal power consumption. Thereby, the frequency of the vibrations should be close to the system's resonant frequency. Currently, there are two main ways of calibrating the vibrators; using accelerometers that are temporarily placed to measure the performance and calibrate, or using a sticker that is inspected while the vibrator is working to determine its amplitude. Both ways are manual and not continuous. The project's goal is to use cameras to determine the peak frequency of the system.

Keywords: Vision, Vibration, Bowl feeder, Automation, Calibration

1. Introduction

B&R Automation (B&R), founded in 1979, currently delivers both hardware and software for equipment such as injection molding machines and vibratory feeders. This project will utilize vision-based solutions, cameras, and lighting equipment offered by B&R to calibrate a vibrator feeder.

When B&R delivers a setup such as a vibrator feeder, it has to be calibrated throughout its lifetime because of the wear on the moving parts, specifically the springs. This calibration is done manually and is time-consuming. It will also not be consistent since each operator can have different views and sensitivity about which is the right calibration at each moment, leading to an inaccurate process. Furthermore, the accelerometer for the calibration is an expensive piece of equipment and can therefore not be put permanently on the vibrators. B&R and their customers are looking for a solution where they can lower the cost of the equipment used for the calibrating. A solution that B&R came up with was to use a camera to control the frequency as it also could be used for other vision-controlled problems.

This leads to the initial problem statement:

How can a machine vision based setup calibrate a vibrator feeder?

1.1 Vibrator feeder

Vibrator feeders are widely used in the manufacturing industry. They are primarily implemented for aligning and feeding different parts into machinery, just as counting and transporting materials. There are principally two types of vibrators regarding their shape: circular and linear. In terms of internal functioning, vibrators can work by electric motors, electromagnets, hydraulic pistons, centrifugal feeders, counterbalancing weights, or spring-connected masses [1]. In this project, the focus will be on a circular and linear electromagnetic vibrator feeder, also known as a bowl feeder, assigned by B&R.

The main parts of an electromagnetic vibrator bowl feeder (figure 1) are the bowl, the electromagnet, the suspension spring, and the drive unit to convert the electrical power into mechanical motion. The bowl is mounted on a spring-loaded base. It contains the elements that will move around the track until their desired orientation is reached caused by the traps around the way and through the vibration of the springs, which are created by the use of electromagnets. On the bottom part, the bowl base supports the mentioned elements with the help of support feet. Finally, the outlet is where the parts and components in the feeder are tracked and ready for production.

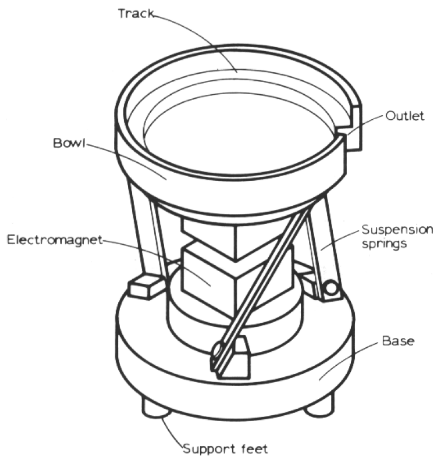

Fig. 1 Vibrator bowl feeder functioning parts

The functioning of an electromagnetic vibrator bowl feeder is based on a magnetic coil set parallel to the springs. The vibration is created through an external power source that magnetizes the coil and exerts force on the armature. Then, the force is transmitted to the bowl that is supported by the spring assembly. Once the bowl is activated, the electromagnetic vibrations have been transformed into mechanical vibrations to create vertical and horizontal movements that help the elements inside the bowl move forward and get aligned into the desired position. The angle of the spring assemblies determines the moving direction of the bowl. The functioning parts are shown in figure 2. [2]

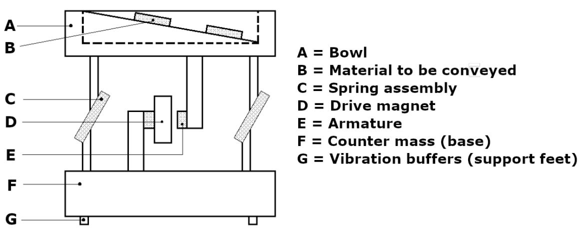

Fig. 2 Vibrator bowl feeder functioning parts [3]

Vibrator bowl feeders' frequency usually runs from 50 to 100 hertz [Hz], depending on the weight of the elements that the machine is working with. Usually, lower frequency works better with heavier elements and vice versa, but a trial and error approach is a more precise way to determine the best frequency for a system. However, since the internal functioning of the machine is a resonant system (spring-mass-system), the vibrator feeder's performance degrades over time as the springs lose their initial tension, resulting in an under-sprung system. For an efficiently functioning vibrator, the vibration frequency needs to be calibrated when first implemented and re-calibrated as it starts to lose efficiency. The re-calibration will ensure that the bowl feeder keeps up with the production speed. [3][4]

The calibration implemented so far with accelerometers is very expensive, and it takes 12 man-hours to calibrate a line of 36 vibrator feeders, equal to 20 minutes per vibrator feeder. Therefore, the following section will analyze the vibrator bowl feeder calibration and calibration methods more deeply in detail in order to find a more efficient calibration approach.

1.2 Calibration

As mentioned in the previous section, calibration is needed because springs lose their internal tension over time. In this section, manual calibration, accelerometer calibration, and visual calibration, as suggested by B&R, will be described.

One method of calibrating the bowl feeder is to use a sticker (figure 3) to determine the current frequency of the bowl feeder. For this, an employee is needed to observe the sticker. The feeder is then calibrated while making these observations. This method is very cheap to implement; however, regular observations and checkups are needed to ensure the bowl feeder is working efficiently, and as mentioned before, it is not an accurate and efficient method.

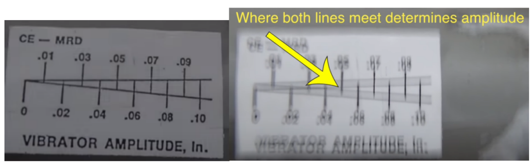

Fig. 3 Sticker used for manual calibration of the vibrator feeder

Another more automated method entails installing accelerometers on the vibrator and measuring the frequency this way. This method does not require a employee to take the measurements themselves. It can be automated to either support self re-calibration or notify the operators or workers when the frequency drifts too far from the most efficient frequency. This method is generally expensive as the sensors need to be sensitive enough to detect the frequency precisely and it needs to be connected to a really fast data collector. However, the accelerometer is a very delicate measuring device and, therefore, very expensive.

The last method described is the idea of using a marker and instead of a human worker doing the observation, a machine vision system would be used. This method consists of a camera checking visual marker position or shape and using this data to determine the frequency of the bowl feeder. Similar to calibration using accelerometers, this process can be automated.

The motivation for using cameras instead of the accelerometers is because this method would be cheaper to implement and therefore present a cheaper alternative to automate the monitoring and calibration of bowl feeders. Furthermore, the camera could potentially provide other solutions, such as checking the amount of elements in the bowl and providing feedback to the closed-loop of the machine. For all these reasons, this project will focus on this method.

1.3 B&R setup

As already mentioned in section 1.1, this project will focus on an electromagnetic vibrator bowl feeder, which consists of a circular and linear vibrator feeder. Besides, the setup used in the lab also contains a conveyor belt connected to the linear vibrator feeder to transport the elements into the next location. The layout can be seen in figure 4. The circular feeder is on the left side, the linear is in the middle, and the conveyor belt is on the right.[5][1]

1.3.1 Modified setup

The setup needs some modifications before the tests can be started. A mount for the camera needs to be added, for this 4040 aluminum profiles was chosen, which allows fast and easy assembly. The finished mounting solution can be seen in figure 4. A potential issue can be the display interfering with the camera or its field of view. This does not happen in the first test, but if there is a need to lower the camera, the display can be easily removed make clearance.

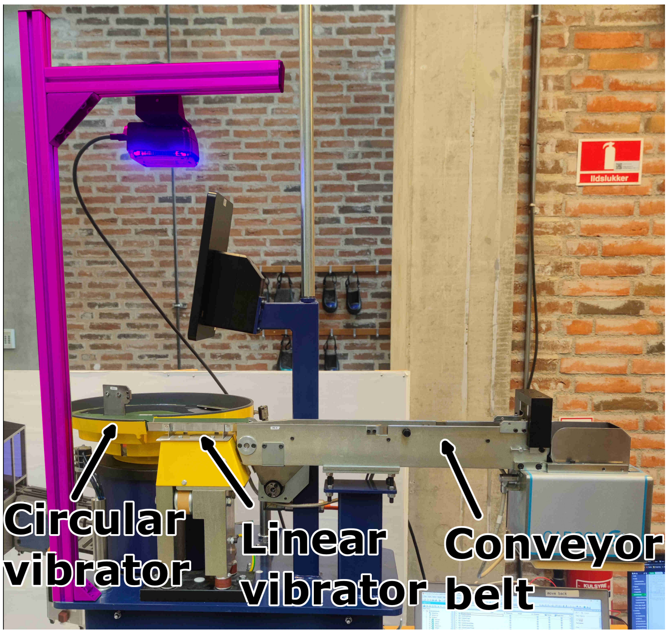

Fig. 4 The camera installed on the vibrator (mount with camera marked as magenta)

With the camera mounted, it is possible to verify if the position allowed for viewing both the linear and circular vibrator. The view from the camera can be seen in figure 5. Two white stickers with a black rectangular dot can also be seen in the figure, one on the circular vibrator (marked with green color) and one on the linear vibrator (marked with red color). These stickers will be used to determine the amplitude and frequency of the machinery by analyzing their different positions when the vibrator is on.

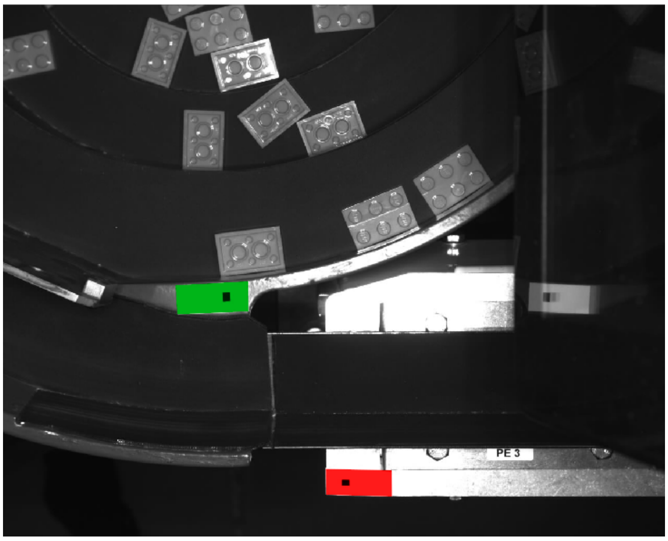

Fig. 5 The view of the vibrator from the mounted camera

A flowchart showing the connections in the new setup can be seen in figure 6. Yellow arrows represent power connections. Some of the power connections and components in the vibrator were omitted for simplicity.

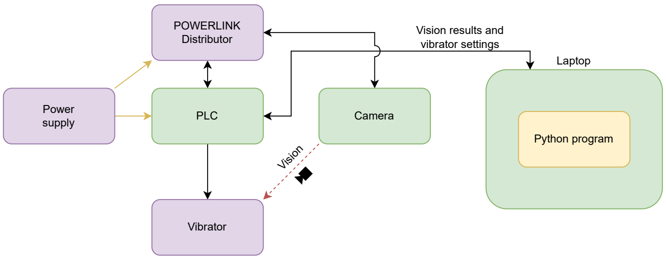

Fig. 6 A flowchart of the lab test setup with a single PLC.

2. Methods

2.1 Possible solutions

There are several possible options for measuring the amplitude the vibrator achieves. The signal does not have to be recreated, and only its amplitude is measured; therefore, the sampling rate does not have to be $f > 2B$, where f is the sampling frequency and B the signal bandwidth [6].

This section will focus on the possible solutions for the vibrator feeder calibration, trying to fulfill the questions from the problem statement. The gathered information from B&R and the plausible options that the group evaluated led to consider these five possible solutions:

- Unsynchronized method
- Phase shift method
- Line scanner method
- Long exposure method
- Synchronized method

2.1.1 Unsynchronized method

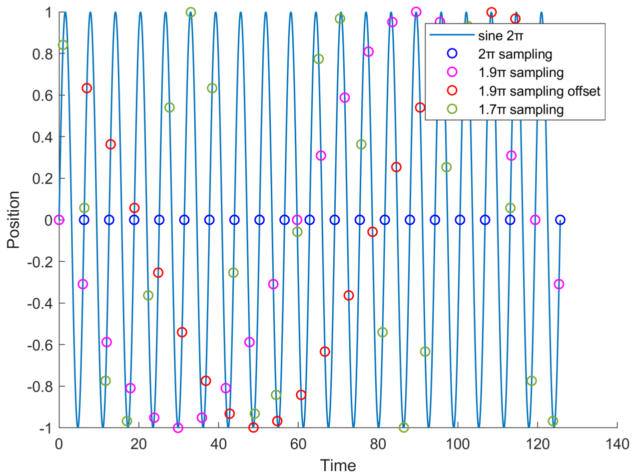

Fig. 7 A plot showing the effects of sampling with a frequency close to the signal frequency

The first approach is quickly taking regular images, the position of a dot on the vibrator would be tracked using vision functions to determine the amplitude. With a initial test, it was determined that the camera could take a picture every 19.2 ms resulting in a sampling rate of approximately 52 Hz. To illustrate the effect of sampling with a frequency close to the signal frequency, a sine wave plot was made in Matlab. From the plot seen in figure 7 it can be seen that with a high enough amount of samples and a sampling rate close to the signal frequency, it is possible to determine the amplitude with accuracy sufficient for this use case, as the frequencies get closer to each other the number of required samples increases.

2.1.2 Phase shift method

When controlling the vibrator, it is possible to synchronize taking pictures with the peaks of the vibrator. The issue with this is that, if there is a phase shift between the drive signal and the physical response of the vibrator, then the measured amplitude will not be accurate and will change based on this phase shift. If the phase shift is dependent on the frequency or power setting, then a calibration will have to be done before every amplitude measurement. The effect of phase shift on the measurement is illustrated on figure 8.

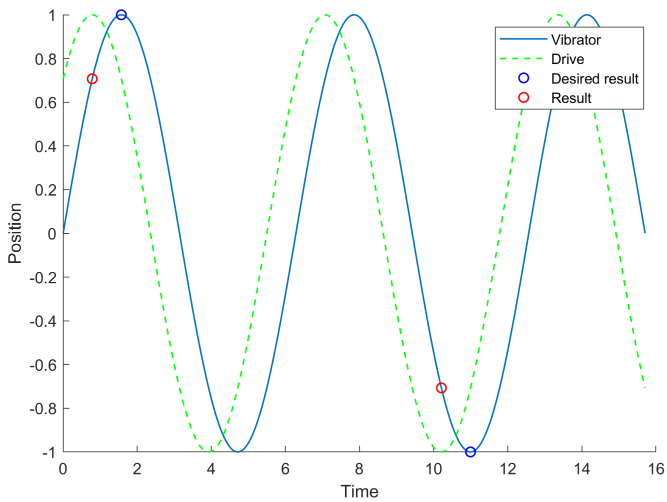

Fig. 8 A plot showing the effects of phase shift on amplitude measurements

The calibration could be done by taking a series of pictures with increasing delay after the peak until the position value stops increasing and then measuring the amplitude using the resulting offset.

2.1.3 *Line scanner method*

The line scanner takes a series of pictures with a set delay between them and combines them into a single picture. The analysis is done afterwards allowing for higher frequency of taking pictures than is possible in the normal mode. The period in which the pictures are taken needs to be at least as long as the period of the signal, otherwise there is a possibility that the peak positions will be missed. The graph seen in figure 9 shows how the length of picture taking period affects the measured amplitude.

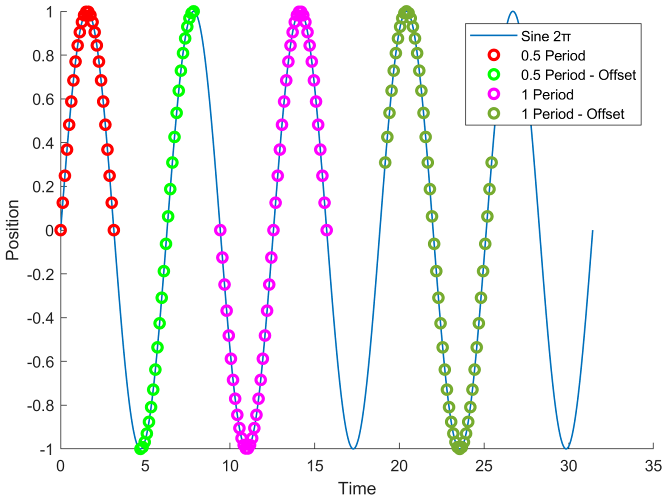

Fig. 9 A plot showing different lengths of picture taking period in relation to the period of the signal.

2.1.4 *Long exposure method*

Another approach is a long exposure, where instead of tracking the dot to determine the amplitude, its size would be used instead. A neutral density filter would be necessary to prevent overexposure due to taking a long exposure picture. The light from the camera should still be used so that the solution is not overly affected by external ambient light. The exposure time should be at least as long as the period of the signal, similar to the line scanner approach. A simulation of the resulting picture can be seen in figure 10. The amplitude can be obtained from formula: $B - A$.

Fig. 10 A plot showing the effects of sampling with a frequency close to the signal frequency

2.1.5 *Synchronized Method*

This method is similar to the unsynchronized vision but now the time at which the picture is taken is synchronized with the PLC time. The pictures are scheduled to be taken at $LastPictureTime + period + increment$. This results in repeatable sampling resolution even if the frequency of the vibration changes. If the number of pictures taken is set until the total increment is equal to period, then the full wave with both the high and low peak will be captured. A simulated plot showing the results can be seen in figure 11. The plot looks similar to the unsynchronized method, but in this method the sampling frequency would always change to be the same relative to the period. The offset sampling is shown to illustrate that the method works regardless of the starting phase which is not determined.

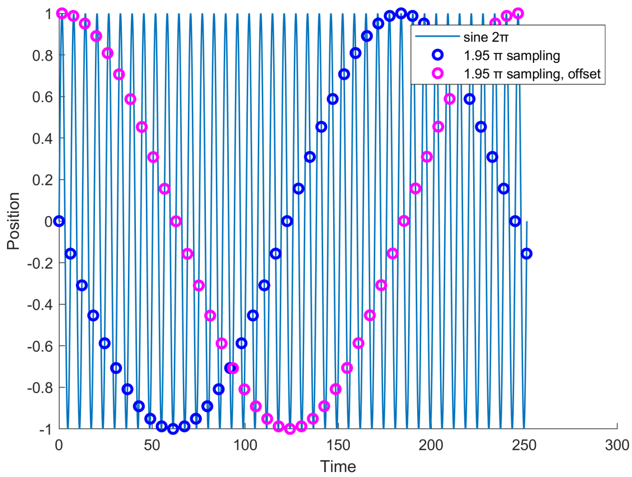

Fig. 11 A plot showing the synchronized method

2.2 Comparison of the Different Methods

To compare the different methods, some initial testing was done. The tests were only done on the unsynchronized, line scanner, and synchronized methods, as the long exposure method acquired extra equipment and the phase shift method was not implemented because of time limitations.

The unsynchronized method does produce results but is lacking in scalability. Its speed depends on the speed of the camera and processing. The method may be inaccurate depending on the frequency of the vibrator, or not work at all, if the sampling frequency matches the frequency of the vibrator.

The line scanner works fast and produces better results than the unsynchronized method. There are however some issues with this method, such as the light pulse duration limit or the photo interval dependent on the exposure time.

Out of the three methods tested **the synchronized method** has the highest scalability and flexibility potential. It can be modified for use on higher frequency vibrators or on cameras with a longer processing time.

2.2.1 Summary

While all methods worked and had similar results, the synchronized method will be used and tested in more detail from now on. This is due to this method having the highest potential for flexibility and improvements.

3. Testing and Results

3.1 Test method description

The 1.3 MP camera is used with a distance of 266 mm from the empty bowl feeder. The tests are done using a frequency sweep program going through 40%-80% power with 10% increment and a frequency range of 49Hz-50.2Hz. The sweep is done in a way that saves time by first doing coarse sweep and then moving to finer sweeps in reduced ranges. There are three sweeps in total, one with increment of 0.16 Hz , next - 0.04 Hz and the final 0.01 Hz. This results in requiring less measurements and having a more detailed end result. The program flowchart can be seen in figure 12.

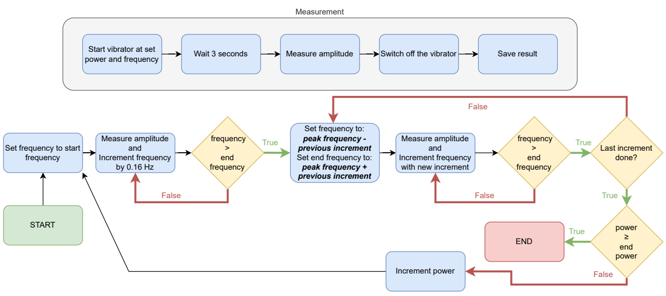

Fig. 12 A flowchart of the frequency and power sweep program

3.2 Power frequency test

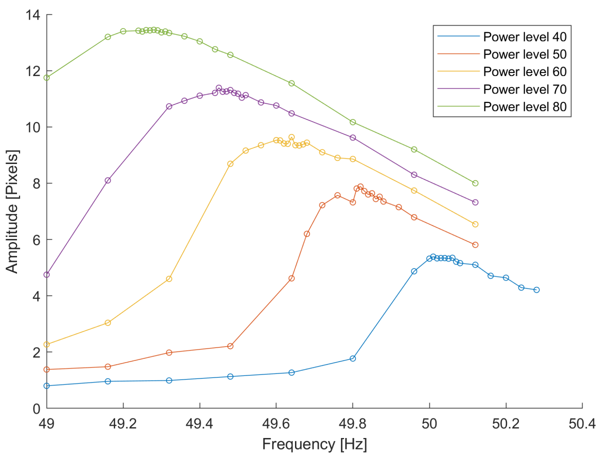

Fig. 13 Line plot of frequency and power sweep

The first test was the power and frequency sweep to see if it can work on different power levels and to see what the results are. The resulting graph can be seen in figure 13. As the individual data points are marked with circles the graph also illustrates how the time-saving sweep is done.

3.3 Optimizing speed

As the method had some unnecessary delays, it was optimized by removing them. This resulted in a decrease of time required to do a single frequency sweep to 108 s from 157 s before improvements. A possibility for even more optimization was also inspected. If the offset is changed from 125 μs to 250 μs half the amount of pictures will be taken, increasing the speed at the cost of resolution. This reduces the time to 89 seconds. The result comparison between the two offsets can be seen in figure 14. The standard deviation in the found peak frequency was 0.0066 Hz for the 125 μs offset and 0.0101 Hz for the 250 μs offset. At this point the starting and switching delays take up the majority of the time (68.25 s for both offsets).

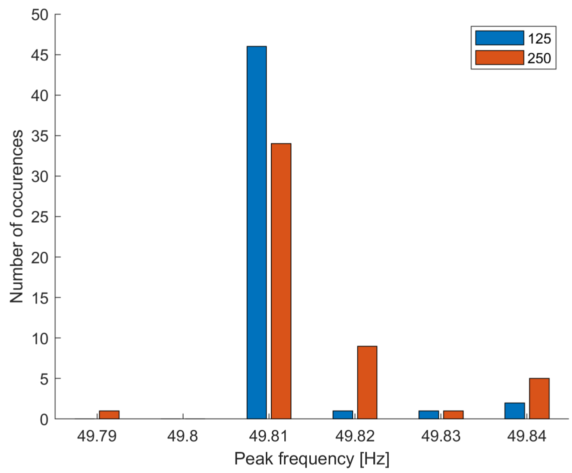

Fig. 14 Bar graph showing the distribution of results for the 125us and 250us offset

The difference in the performance of the methods is not big but neither is the speed difference. This means that either one of the offsets could be used based on what is the highest priority - time or calibration accuracy. For further tests the 125 μs offset will be used as it provides better results.

3.4 Resolution

One of the important things to determine is if the resolution has a big influence on the results. B&R wants the camera to see as much as possible of the bowl feeder, but they don't want to lose precision when calibrating. The test is done to look into the how much the precision changes when the resolution is changed. Until now the resolution has been approximately 9.7 $\frac{pixels}{mm}$.

3.4.1 Higher Resolution

For the following tests in this section the resolution will be 31.14 $\frac{pixels}{mm}$, the increase is due to using the 5.3 MP camera.

The higher resolution camera has a smaller standard deviation (0.0437 pixels compared to 0.1121 pixels), on a 50 sample test of power 50% and frequency 49.8 Hz. This is expected as with a higher pixels per millimeter resolution the position can be determined more precisely.

3.4.2 Lower Resolution

To test how much the resolution can be decreased before the results are severely affected, the first camera was moved up as far as the current setup allows. This results in a resolution of approximately 4.9 $\frac{pixels}{mm}$. First a single run was done to see if it still works. Afterwards 50 frequency sweeps were done at power level of 50%. The results can be seen in figure 15.

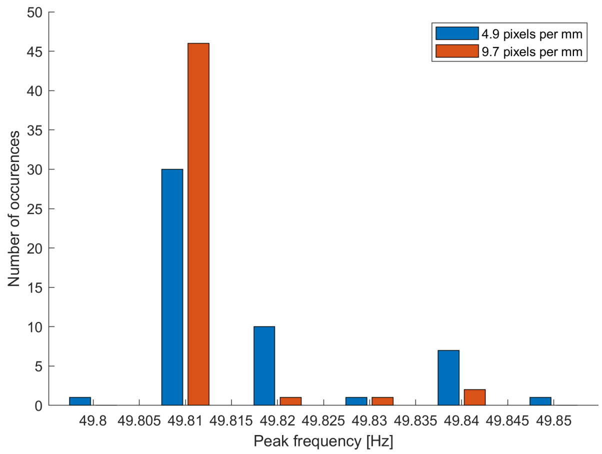

Fig. 15 Peak frequencies found from 50 frequency sweeps at a lower resolution, comparison with standard resolution

The resulting standard deviation is 0.0118 Hz. The standard deviation for the same test on the resolution of 9.7 $\frac{pixels}{mm}$ was 0.0066 Hz.

The method still works with the lower resolution camera although the standard deviation of the found peak frequencies is higher, it is low enough that the solution is still accurate enough. Our setup does not allow to decrease the resolution further, so the test ends here.

3.5 Linear vibrator

The power and frequency sweep was ran for the linear vibrator at a range of 51.5 to 54 Hz and powers from 40% to 80% with an increment of 10%. At power level 40% the peak frequency is close to the limit of 54 Hz. The graph shown below (figure 16) has the results of the power and frequency sweep. The results show that the method also works on the linear vibrator.

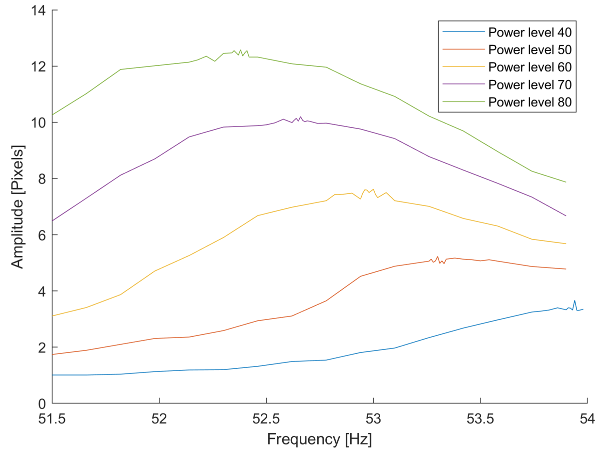

Fig. 16 The results of a power frequency sweep for the linear vibrator

In order to see if the method gives consistent results 50 sweeps were ran on power level 50%. The frequency range was reduced to 53-54 Hz in order to reduce the required time. The found peak frequencies can be seen in figure 17. The standard deviation in the found peak frequencies is 0.0632 Hz.

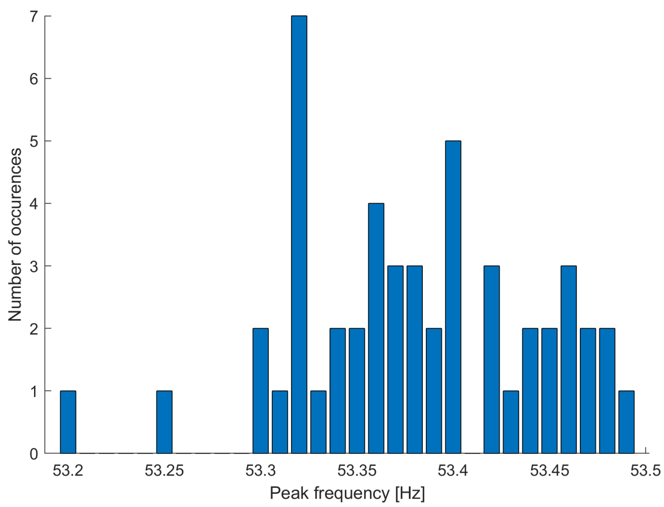

Fig. 17 The results of a 50 frequency sweeps at power 50%

The method works on the linear vibrator but the results are less consistent than the circular vibrator. This may be due to the amplitude being slightly lower than on the circular vibrator. Another reason for this may be that the frequency response of the linear vibrator is different. On the linear vibrator the range of frequencies where the amplitude is high is flatter (there are more frequencies with similar amplitude near each other).

4. Conclusion

The focus of this paper has been to analyze the different aspects of a vision-based calibrations method. In order to do this, a description of the vibrator bowl, different calibration methods, and the test setup were conducted. From this description, it was found that the current way of doing the calibration was inefficient as it took up to 12 man-hours to calibrate a line. Furthermore, it was determined that B&R wanted to do the calibration by utilizing a camera.

This led to chapter 2.1, where five different solutions for determining the amplitude were proposed. After some initial tests, it was determined that the synchronized method was best suited for further testing.

In chapter 3, the synchronized method was tested for different aspects. First, a power frequency test was conducted to determine if the method could detect the amplitude at different power levels.
Next, a test was conducted to optimize the time taken for a single frequency sweep. This led to a decrease in run time to 108 s from 157 s.
Afterward, a test on the camera resolution was done. It was determined that the method still works with higher and lower resolutions. The lower resolution doubled the standard deviation; however, it only increased to 0.0118 Hz.
Lastly, a test was conducted to determine if the synchronized method would also work on the linear vibrator. Here the results showed that the method also worked, as it could determine the amplitude.

Acknowledgement

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