

Diploma Work

Documentation

3D disc scanning and multipoint datasets



Project from 31/05/2011 to 12/8/2011

**Bachelor Project in electronics
at Lawrence Berkeley National Laboratory, California, USA**

Student:	Marc Stadelmann
Supervisors:	Carl Haber, Earl Cornell
Responsible professors:	Wolfram Luithardt, Ottar Johnsen
External expert:	Luciano Sbaiz

Abstract

Sound archives and museums are holding a lot of old, valuable, mechanical recorded audio record carriers. The problem with those records is that they cannot be played on regular players anymore, because they are in a bad condition which produces poor sound quality, and even more important, the stylus of the mechanical audio player could damage those records. In order to restore audio out of such records, Carl Haber and Earl Cornell developed an optical reading system at LBNL. An optical 3D scanner measures the surface of the sound carrier. By processing this data with different algorithms, sound can be reproduced.

The goal of this project is to adapt the current system for multiple pass scans, which should increase the overall sound quality.

Zusammenfassung

Tonarchive und Museen besitzen oft wertvolle mechanische Tonträger wie Schallplatten oder Zylinderaufnahmen. Das Problem mit diesen Tonträgern ist, dass sie durch ihren oft nicht mehr sehr guten Zustand mit den klassischen Spielern nicht mehr wiedergegeben werden können. Ein weiteres Problem ist, dass die Wiedergabe mit einem mechanischen Spieler den Tonträger weiter beschädigen könnte. Um diese Aufnahmen trotzdem für uns zugänglich zu machen haben Carl Haber und Earl Cornell ein System entwickelt, welches diese Aufnahmen ohne sie zu berühren in eine digitale Audiodatei umwandelt. Dazu wird die Oberfläche des Tonträgers mit einem 3D Scanner ausgemessen. Aus den gemessenen Daten wird eine topografische Karte der Oberfläche des Tonträgers erstellt. Durch Verarbeitung dieser Daten mit verschiedenen Algorithmen kann aus dieser Karte eine Audiodatei erstellt werden.

Das Ziel dieses Projektes ist es, dass momentan bereits vorhandene System für mehrfach Scans anzupassen. Mehrfach Scans werden angewandt um mehr Datenpunkte zu erhalten, dies erlaubt später eine bessere Unterscheidung zwischen guten und schlechten Datenpunkten.

Résumé

Dans des musées et des Archives sonores il y a beaucoup des vieux, précieux supports d'audio mécanique. Le problème avec ces enregistrements est que ils ne peuvent plus être lus avec des lecteurs réguliers, parce qu'ils sont en mauvais état et ça produit une qualité sonore médiocre. En plus de ça, il y a le risque que le lecteur mécanique pourrait endommager ces enregistrements. Afin de restaurer ces enregistrements, Carl Haber et Earl Cornell ont développé un système de lecture sans contact à LBNL. Un scanner optique 3D mesures de la surface du support sonore. En traitant ces données avec des algorithmes différents, le son peut être reproduit.

L'objectif de ce projet est d'adapter le système actuel pour les scans passent multiples, ce qui devrait accroître la qualité sonore globale.

Table of contents

1	INTRODUCTION	3
1.1	CONTEXT	3
1.2	INTRODUCTION TO THE PROJECT	3
1.3	OFFICIAL DESCRIPTION	4
1.4	CURRENT STATUS OF THE PROJECT	5
1.6	STRUCTURE OF THIS REPORT	5
2	BASIC INFORMATION	6
2.1	HISTORY	6
2.3	CLASSICAL DISC READING METHODS	8
2.4	OPTICAL READING	10
2.5	OPTICAL 3D SCANNING SYSTEM AT LBNL	11
2.5.1	Overview	11
2.5.2	Equipment	12
2.5.3	Multiple Point Line Sensor	13
2.5.4	Sound reproduction process	14
2.5.5	Data acquiring	15
2.5.6	Data distribution in multiple pass scans	15
2.5.7	Disc data processing – PRISM	16
3	HARDWARE PART – DATA ACQUIRING	17
3.1	GENERAL PROBLEM ANALYSIS	17
3.1.1	Z-offset in multiple pass scans	17
3.1.2	Focusing system	18
3.2	REALIZATIONS	20
3.2.2	Tool to analyze the gathering files: 3D-Tools_compare.vi	23
3.2.3	Z-axis control: 3D-Tools_focus_v8.vi	24
3.2.6	3D-Tools_global.vi	28
3.2.7	3D-Tools_scan.vi	29
3.2.8	Sub VI's	30
3.3	HOW TO SCAN A DISC	31
3.4	MEASURES, TESTS AND FURTHER DEVELOPMENT	33
3.4.1	Test of the gathering focus	33
3.4.2	Test of the MPLS Focus	35
3.4.3	Dependence of external factors - room temperature	36
3.4.4	New scanning method: dithering	40
3.5	CONCLUSION	44
3.5.1	Future work suggestions	44
4	SOFTWARE PART – DATA PROCESSING	45
4.1	GENERAL PROBLEM ANALYSIS	45
4.1.1	MatchPass	45
4.1.2	FitLine	46
4.2	REALIZATIONS	48
4.2.1	Adaptations in the GUI	48
4.2.2	MatchPass V3	49
4.2.3	FitLine VM	50
4.3	TESTS AND COMPARISONS	51
4.3.1	Performance of MatchPass V3	51
4.3.2	Comparaison FitLine V2 – FitLine VM	53
4.4	CONCLUSION	55
4.4.1	Quantitative comparison of the different focusing systems	55
4.4.2	Future work suggestions	56
5	ACKNOWLEDGMENTS	57
7	LIST OF FIGURES	58
8	APPENDICES	60

1 Introduction

1.1 Context

This paper contains all the documentation of the Bachelor thesis of Marc Stadelmann on an audio project about extracting sound out of a gramophone record.

The project started on the 29th of May and ends on the 12th of August 2011, it takes place at Lawrence Berkeley National Laboratory (LBNL), California.

1.2 Introduction to the project

Nowadays it's almost trivial, that everyone has their preferred songs at home on CDs, on a portable music player or even on a cell phone ready to listen to it at any time. Today's data storing possibilities are immense. Micro SD cards (15 mm × 11 mm × 1.0 mm) which fit in almost every more or less modern cell phone consist today of about 32GB of data space. This corresponds to around 10'000 songs. However such possibilities have not existed for a long time. If we're looking from the "IPOD-era" back to the CD's and tapes we arrive to a point, where sound recording and reproducing was especially difficult. Sound was recorded on mechanical carriers such as cylinders or later discs. First with full mechanical and later with electro-mechanical playing devices this sound could be reproduced. With new technologies arriving over the years, those players disappeared slowly, but many records were archived. In museums all over the world many audio collections are archived, collecting dust and waiting to be played. For example here in California a 100 year old documentation about the Yahi Indians which was recorded on 51 cylinders is currently being digitalizes.

The problem with these valuable old records is that the mechanical players may damage them. This is especially a big problem for records made of delicate materials such as wax cylinders. Another problem with such records is that they often are already damaged or broken. By playing them with a regular player, the stylus will not follow the groove as it should and the sound quality will be poor. In order to listen to such records without damaging them, Carl Haber and Earl Cornell developed an optical reading system to digitalize them at LBNL. The system is fully optical. This means the record is read without touching it. This work is done by an optical 3D scanner which scans the depth of the grooves of the records and draws a surface map. By processing this map with different algorithms, the recorded sound can be reproduced.

At the moment the system works, but the sound quality is dependent on the different conditions and parameters of the record. For example shiny records cause problems for the 3D scanner. In order to receive a better sound quality, a multiple pass scanning system was developed. By implementing this multiple pass procedure, several issues like offsets between the different passes and tracking problems were encountered. The goal of this project is to analyze these issues for disc scanning, not cylinder scanning, and if possible to resolve them.



Fig. 1 - Player history

1.3 Official description

3D disc scanning and multipoint datasets

Abbreviation: Berkeley3Dmulti

At Lawrence Berkeley National Laboratory, Carl Haber and his team has been working on the extraction of sound from phonographic records. Students from EIA-FR have participated in the work now for several years.

Part 1: Interleaved depth acquisition

Previous work indicates that the intrinsic 10 microns spacing of the 3D probe measurements is insufficient, particularly on discs. This has led to the "multi-point" data collection strategy. We do a scan and then we shift the probe either 2.5 microns or 5 microns in order to interleave the measurements. There are however technical issues with combining multi-pass data due to the differing pass-to-pass depth (Z) offset. We will investigate a series of approaches to this issue:

A. Instead of using the Z-offset autofocus on all passes we will log the Z profile on the 1st pass and then use it as a driving function for Z height on the subsequent passes. Does this work? We would need to develop the real-time software to control the motors based upon the first pass measurements.

B. By comparing the depth of several passes, the offset between the passes can be estimated and compensated. T. Mueller (EIA-FR bachelor student from 2010) developed a set of tools and analysis procedures to use a rotated 3D probe to scan discs. As we rotate the probe the points get closer together across the groove (perpendicular). Will the Mueller correction function for time shifts still work with interleaved scanning? The modifications necessary must be analyzed and implemented.

Part 2: Adaptive filtering and parameter optimization:

A key aspect of the 3D data analysis is to properly choose between good and bad data points. We believe this can be best done by performing multiple passes through a data subset and searching for a noise/signal optimization based upon certain filtering cuts. We need to implement this as a semi-automatic process on the data sets. The project would involve data analysis, algorithm development, use of statistical methods, and minimization techniques.

The project will take place at Lawrence Berkeley National Laboratory.

Keywords: Image processing, sound processing, audio

Proposed by: Lawrence Berkeley National Laboratories, University of California, Berkeley

Filière(s) : Electronique Génie électrique

Internal responsible: Ottar Johnsen, Wolfram Luithardt

External responsible: Carl Haber, Lawrence Berkeley National Laboratory

Expert: Luciano Sbaiz

1.4 Current status of the project

Over the last several years, a lot of progress has been made on this project either from LBNL or EIA-FR students working on it for their thesis.

In 2008 **Sven Hezel** and **Severin Nowak** (1) implemented different algorithms for cleaning and line fitting. They worked with an older version of the probe and used the program 3DSEVEN which has been replaced by PRISM2010 for the data analysis.

In 2009 **Philippe Ballestraz** and **Raynald Sydoux** (2) scanned the disc with probe tilted 20 degrees on the vertical axis. This technique was used to get better data, which was necessary because the old version of the probe had not enough light power to perform a good scan on the inside of the 45° grooves walls. With the new and better probe, MPLS180 V2, this technique is no longer necessary, because the new probe has more light power and is therefore able to scan the groove direct from the top.

Last year, in 2010 **Tobias Mueller** (3) and **Adrien Nicolet** (4) improved several parameters of the whole project and were thereby able to produce better sound quality than before. They implemented the new version of the Probe MPLS180V2 and took the first measures with it. Further, they worked on the algorithms and processing procedures of PRISM2010 and implemented some new features. At the end of their work, they were able to scan discs which could not be scanned before.

One of the most important utilities of this project is PRISM. PRISM is a software tool which takes the scanned data, tracks the grooves, finds the center of the grooves and finally produces the audio file. PRISM has been edited over the last few years by different people and it is now a very powerful tool. PRISM is able to handle different types of discs and cylinders. Several sound extractions have been made successfully.

1.5 Goals of this project

At the moment, the 3D scanning system works well for the cylinder scanning. The disc scanning system is functional as well, but the quality for different disc varies a lot. The goal is to increase the overall quality of the sound. Therefore LBNL started to perform multiple pass scans on discs. This means, that every part of the disc is scanned four times and the probe is shifted 2.5 microns between each scan which results in a data point every 2.5 microns instead of every 10 microns. Having more data points allows for the identification and exclusion of bad points. When implementing this multiple pass scan, different issues were detected.

First, the data from the different passes have a Z-height offset due to imprecisions in the laser based autofocus system. This is due to a variable response of the distance sensor for each of the different passes and latency of the focusing motor stage. To solve this problem, a tool should be developed which logs the focusing data of the first pass, and uses this same data for the next three passes. By doing this, the optical scanning device should be positioned at exactly the same distance from the disc for all four passes. Even if the focusing position in the first pass was not at the optimal height above the disc, this positioning error should be the same for all of the four passes.

Once the data acquiring system is improved, there are still issues with processing this data left. PRISM, the program which tracks the grooves and finds the centers to produce the audio file, is optimized for single pass scans. Even if the parameters are adapted, PRISM has difficulty finding the center of the grooves and therefore the audio quality is not very good. The second goal of this project is to analyze and adapt the different tracking and fitting algorithms of PRISM for multiple pass scan data.

1.6 Structure of this report

This report starts with a short overview of the phonographic records, its history and how they are recorded and played. Next the report is separated into two main parts: 1) the hardware part which contains everything about data acquiring and focusing of the scanner and 2) the software part which contains everything about how the acquired data is processed to produce the audio files.

2 Basic information

This chapter contains general knowledge about phonographic records, different available discs and the optical recording system of LBNL which is necessary to understand the remainder of the report.

2.1 History

The earliest known sound recording device, the Phonautograph was invented in 1857 by Édouard-Léon Scott de Martinville. The phonautograph collects the arriving sound with a horn. A membrane was attached to this horn which vibrated a stiff bristle which finally inscribed an image on a cylinder. Unlike the later invention of Thomas Edison, the phonautograph was not able to play sound. Its recordings were only used for scientific investigations of sound waves.

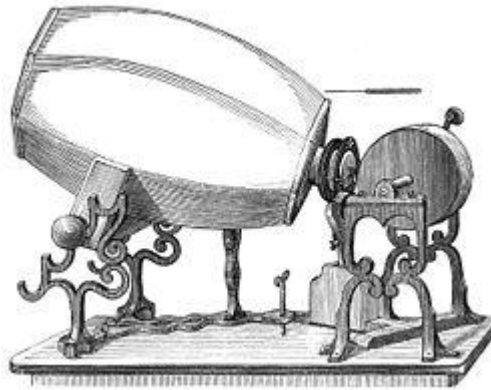


Fig. 2 - Phonautograph (5)

Twenty years later, in 1877, Thomas Edison developed the Phonograph. Both devices looked similar and they also work similarly. The big advantage of Edison's device was that it could not only record sound, but also played sound. By rotating the cylinder, the stylus followed the groove and moved up and down. This method was called “hill-and-dale” (Fig. 6 a).



Fig. 3 - Edison and phonograph (5)

During the 1880ies Alexander Graham Bell and other inventors have developed more different kinds of recording devices. For example Bell developed a device which was similar to Scotts Phonautograph, but instead of using a Horn he used a human ear (including the internal parts) from a cadaver as sound collector. Ten years later in 1887, Emile Berliner commercialized a device to record sound not on a cylinder, but on a disc. Instead of “coding” the sound information in the height of the groove, the Berliner method used the lateral movement of the groove (Fig. 6 b). The quality of those discs was relatively poor at the beginning. For this reason, discs were not used until 1894, after Eldridge R. Johnson had made some improvements to the disc system. From that time on until the 1920s both systems co-existed. After 1930 gramophone records became the leader on the market and the cylinders disappeared.

2.2 Different sound carriers

Over the years, different kinds of discs have been used. They differ from each other in parameters like size, material they are made from, playable time duration and revolutions per minute.

At the beginning, the speed range started at 60 rpm (revolutions per minute) and went up to 130 rpm. After 1925, the speed was standardized at a nominal speed of 78rpm. This speed was decided upon as a compromise between countries, such as the United States, using 60Hz electricity and the rest of the world. The 78rpm speed in the 60Hz countries could be obtained by using a 3600 rpm synchronous motor with 46:1 gearing. This produced a speed of 78.26rpm. In the countries using 50Hz electricity the speed was obtained by using a 3000 rpm motor and 77:2 gearing. This produced a speed of 77.92 rpm.



Fig. 4 – Different types of disc records (6)

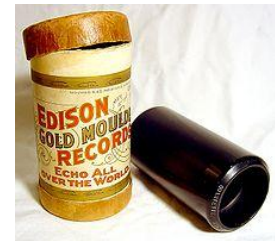


Fig. 5 - Phonograph cylinder (6)

The following table gives an overview of the different sizes of discs and the speeds which were produced.

Format	Revolutions per minute	Disc diameter	Time duration per side
Single	45rpm / 33½ rpm	7" (17.78 cm)	ca. 4 min. to 5 min.
10" Single	45rpm / 33½ rpm / 78rpm	10" (25.4 cm)	ca. 3 min.
Maxi-Single	45rpm / 33½ rpm	12" (30.48 cm)	ca. 16 min.
Extended Play	45rpm / 33½ rpm	7" (17.78 cm) / 12" (30.48 cm)	ca. 5min to 15min
Long Play	33½ rpm / 45rpm	12" (30.48 cm) / 10" (25.4 cm)	Ca. 20min to 25min

The big difference between the disc and the cylinder records is the way in which the sound information is contained. In a cylinder, the height of the groove represents the audio whereas the audio information for discs is contained in the grooves lateral position.

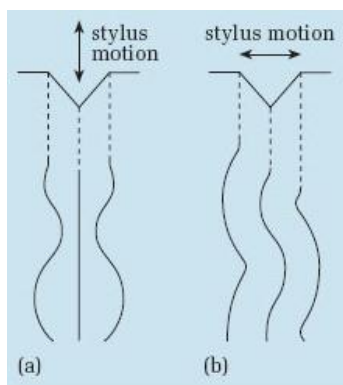


Fig. 6 - Stylus motion (7)

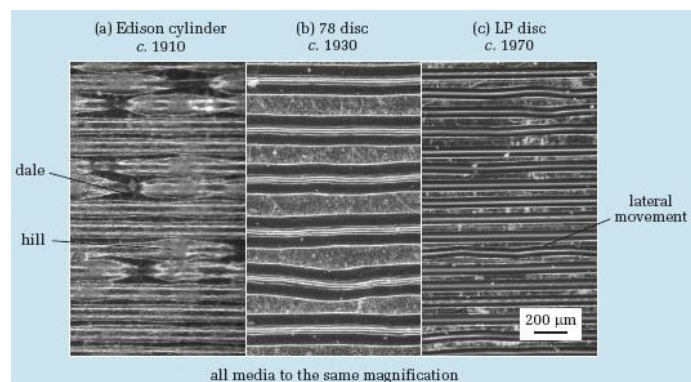


Fig. 7 - Different grooves (7)

The grooves of the 78rpm discs, which are being used in the current project, are about 70 microns deep and the angles of the slopes are 45 degrees.

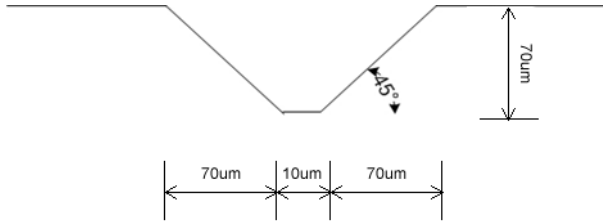


Fig. 8 - Groove dimensions of 78's (4)

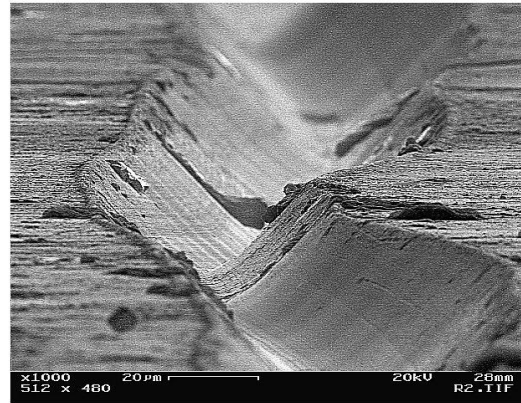


Fig. 9 - Gramophone groove

2.3 Classical disc reading methods

Acoustical gramophone

The first gramophones, made around 1887 were fully mechanical. The disc had to be displaced in rotation with a lever which had to be turned by hand. The reading of the sound was done by a needle which followed the grooves on the disc. That needle was connected by a lever-system to a membrane which was connected to a horn. The playing mechanism was exactly the inverse of the recording.



Fig. 10 - Acoustical gramophone (8)

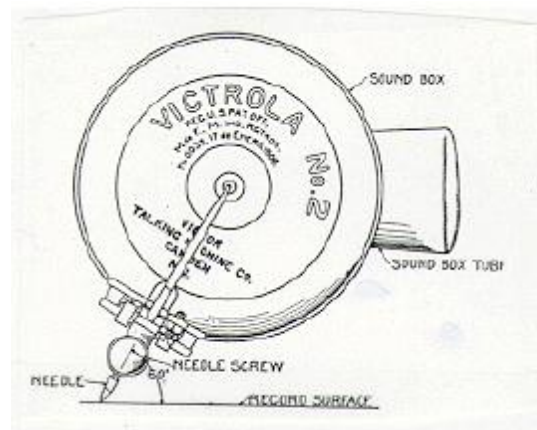


Fig. 11 - mechanical sound reproduction

Piezoelectric cartridges

The first electric phonographs made use of piezoelectric crystals to generate the sound. The mechanical movement of the stylus, due to the lateral movement of the groove on the disc, caused one of the crystals to expand and the other crystal to compress. As a result an electrical voltage was produced by the crystal. The problem with such pickups was the linearity of the output, which produced unwanted distortion in the sound. This system was developed in about 1925.

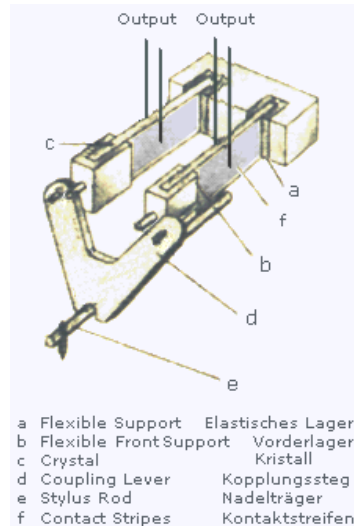


Fig. 12 – Piezoelectric reading head (9)

Magnetic cartridges

Magnetic cartridges were produced in two different variants. The needle was either connected to a moving magnet or to a moving coil. Both systems took advantage of magnetic induction. Magnetic cartridges were produced 25 years after the development of the piezoelectric cartridges and replaced those in all Hi-Fi systems. After 1950, piezoelectric cartridges were only used in low cost equipment. Compared to the piezoelectric cartridge, magnetic ones have different benefits such as less use of the disc and an output which was more stable. However the output voltage was lower, so greater amplification was necessary.

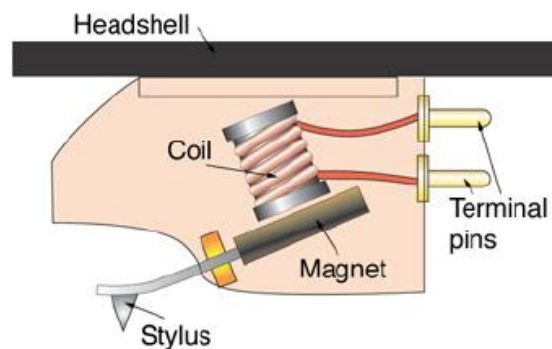


Fig. 13 - Magnetic cartridge (10)

Strain-Gauge cartridges

A strain-gauge or “semiconductor” cartridge does not produce an electrical current itself. It acts more like a variable resistor. The strain-gauge changes its resistance by bending it. So the stylus is connected mechanically to the strain-gauge and with the lateral movement of the groove it changes its resistance. This variable resistance is then used to modulate an “external” voltage.

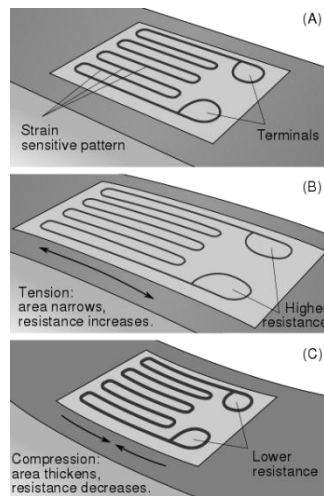


Fig. 14 - Strain-Gauge (11)

The main advantage of this system was that there were no direct connections from the cartridge to the preamp and therefore it was less sensitive to “hum” because there were no magnetic parts used.

2.4 Optical reading

Two different approaches of optical disc scanning were made over the last few years. The 2D “image” scanning method and the 3D “surface” scanning method.

The 2D scanning method consists of acquiring a high resolution picture of the disc's surface. This method is used in the project called IRENE (Image, Reconstruct, Erase Noise, Etc) at LBNL.

A similar project called VisualAudio (12) took place at the University of Applied Sciences in Switzerland.

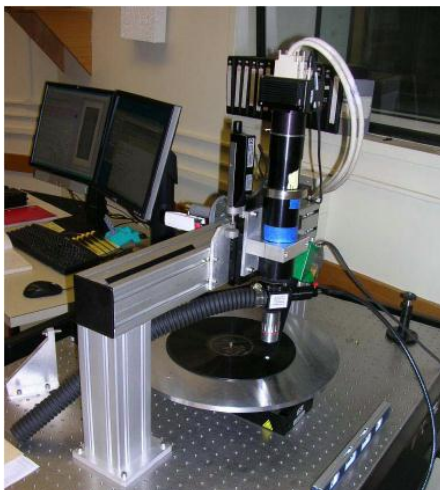


Fig. 15 - 2D disc scanning IRENE

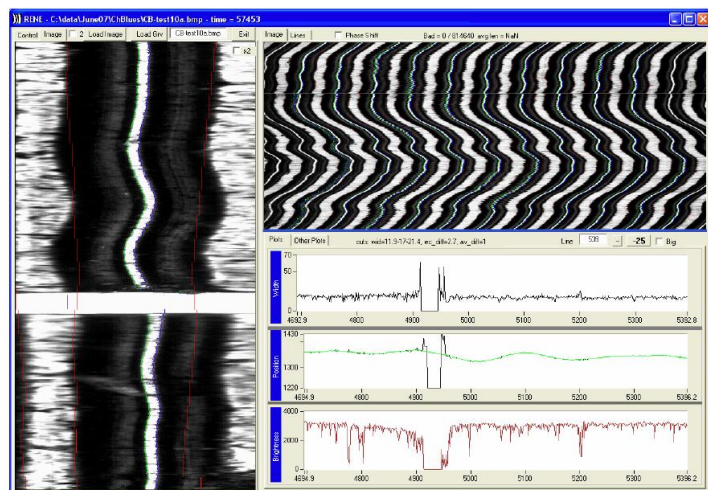


Fig. 16 - Irene software

The 3D scanning method uses an optical probe to create a digital topographic map of the disc. So the probe is measuring depths and not colors. Fig. 17 show the result of one measurement with a 3D probe. The heights of the 180 orange bars correspond to the depth of the disc at 180 different points which are measured simultaneously. Rotating the disc and saving this depth data in a defined spacing creates this topographic map. By using different algorithms to compute the measured points, the grooves can be tracked and the sound extracted.

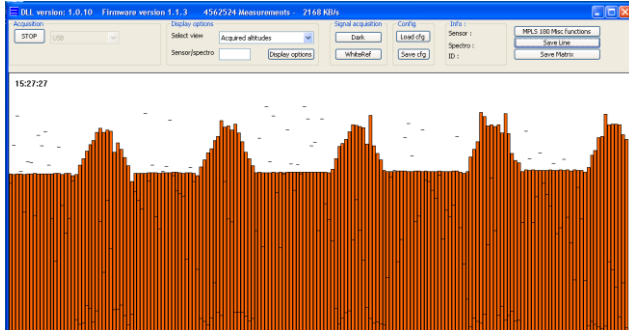


Fig. 17 - 3D scanning data

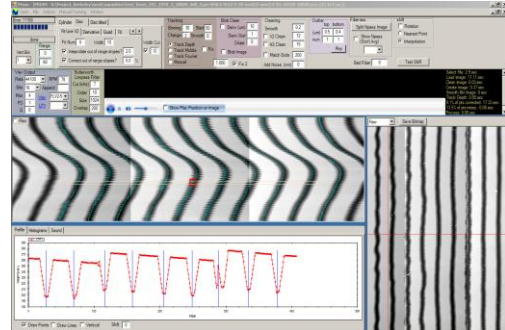


Fig. 18 - 3D software PRISM

2.5 Optical 3D scanning system at LBNL

2.5.1 Overview

The 3D scanning method consists of drawing a surface map of the disc. An optical device, the MPLS180 (multiple point line sensor 180 – we call it the probe) scans simultaneously 180 points in a spacing of 10 microns (Fig. 24). This device is mounted perpendicular over a rotation stage, where later the disc is placed. By turning and translating the rotation stage, the whole disc can be scanned without touching it. To scan one disc with this method, it takes around 40 minutes.

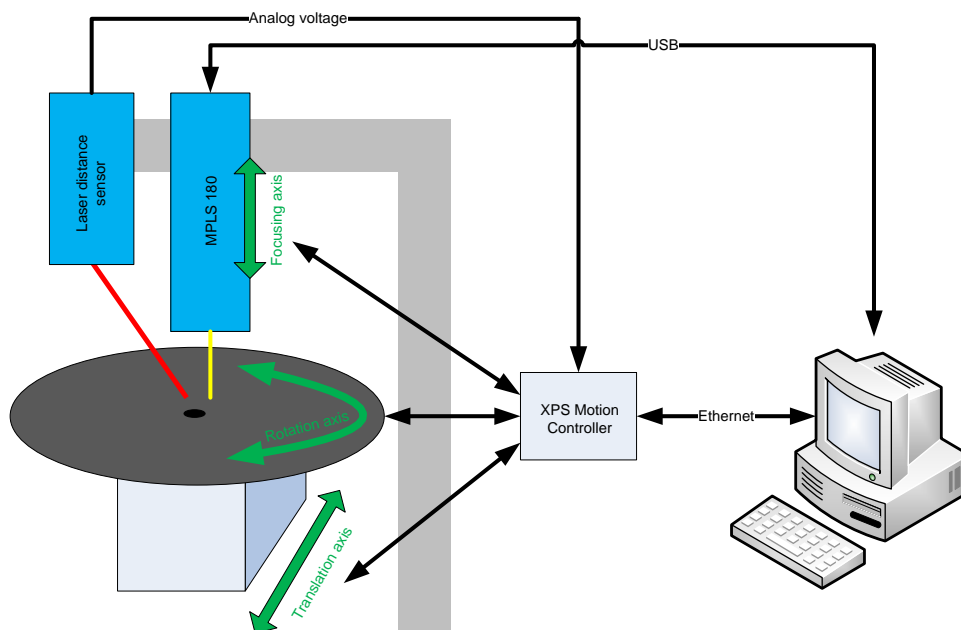


Fig. 19 - Optical scanning system at LBNL

The MPLS has a limited range of 350 microns. However the discs are usually not 100% flat, most of the records are warped. Therefore the shape of a disc can be up to a couple of millimeters. To make sure that the disc is not moving out of range of the MPLS, the height of the MPLS is adapted by a laser based auto focusing system. All the movements of the different systems are controlled by a XPS motion controller.

2.5.2 Equipment



Fig. 20 – 3D Scanning system

Fig. 21 - Keyence distance sensor
with controller

Fig. 22 - XPS motion controller

The system is composed out of three main parts: the MPLS180, the laser distance sensor and the XPS motion controller.

Device	Type	Description
Laser distance sensor	Keyence LK-G157	Measures the distance from the top of the disc to the focusing stage to adjust the height of the probe.
Probe	MPLS180 V2	Multiple point line sensors. Scans the surface of the disc.
Motion controller	Newport Motion Controller XPS	Controls all the movements and provides several AD/DA ports which are used for analog tracking.

2.5.3 Multiple Point Line Sensor

MPLS stands for multiple point line sensors. This device contains 180 light spots and receptors which measure 180 points in a line with spacing of 10 microns. The diameter of one point is about 2.5 microns. The optical head of the MPLS180 is connected to its console by two strings of 180 fibers. One of the strings sends the light over a chromatic confocal lens to the probe; the other string returns the reflected light to the console. The console is connected by USB to a computer where the acquired data can be downloaded. The MPLS returns for all 180 points two different results, the depth and the energy.



Fig. 23 - MPLS180

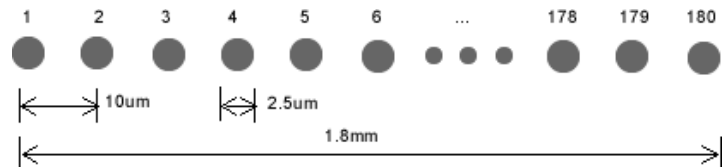


Fig. 24 - MPLS 180 data points

Each of the 180 white light source pinholes is imaged through a common chromatic objective, into a continuum of monochromatic images along the optical axis, thus providing a series of “color coded” optical axes. When an object is placed in these colored fields, a unique wavelength is perfectly focused at its surface for each point, and then efficiently reflected into the objective. These monochromatic light beams go through a series of filtering pinholes into an array of spectrographs. The analysis of the wavelengths that have passed through the filtering pinholes allow for each point to accurately determine its position in the measuring field. (13)

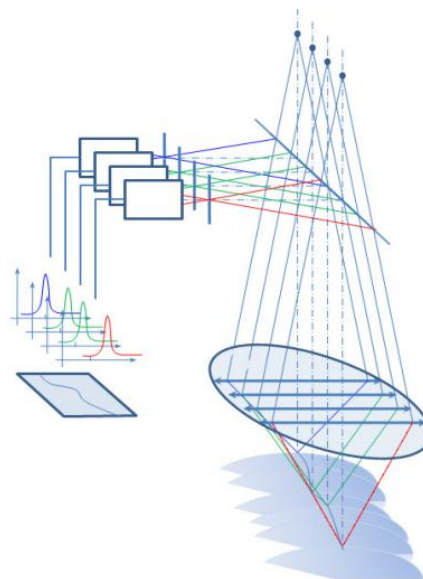


Fig. 25 - MPLS: chromatic confocal sensor

2.5.4 Sound reproduction process

Four main steps are executed in order to reproduce sound out of a mechanical sound carrier.

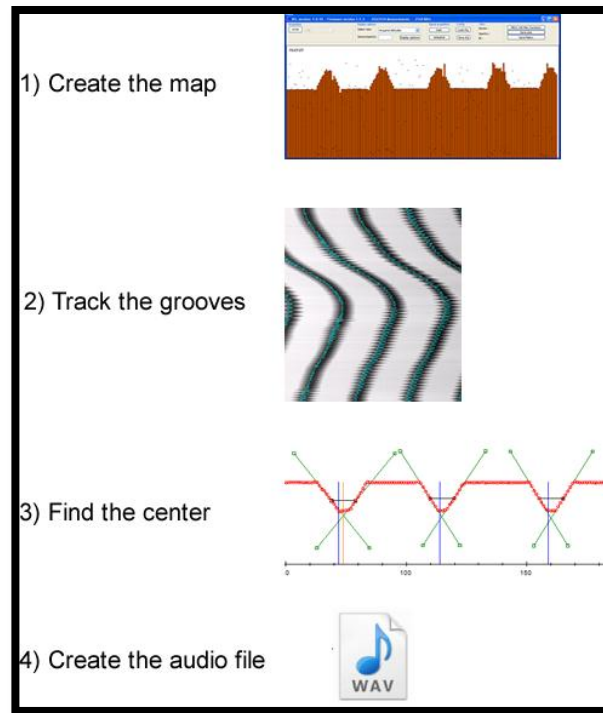


Fig. 26 - Sound reproduction

First the disc has to be scanned. This process takes most of the time, around 40 minutes per disc depending on the scanning parameters. This process is controlled by a LabView application (Fig. 27). The outputs of this process are collected in two files. One contains all information about distance of the scan (the file contains a *.pri ending) and the other contains the information about the point's energy (*.bri). The energy file is used for purposes such as finding the upper level of the disc. Since the disc is flat in this area, more light is reflected and therefore the energy of the points is much higher. Once those files are created, the Visual C# based program PRISM (Fig. 29) can load the files and process them in various ways depending on the entered parameters. First it tries to track the grooves (see blue lines in Fig. 26 on second image). If this process is unsuccessful due to the low quality of the data, PRISM provides a manual tracking mode where the user can track the grooves with the mouse. As soon as the grooves are tracked, PRISM tries to find the grooves center. Therefore different approaches are available. The most common method is "Fit line V2". By computing all of the center points together, a wav file is created and the once mechanical recorded sound is now digitalized.

2.5.5 Data acquiring

A LabView tool collects all the necessary parameters to scan a disc. It controls the rotation and translation of the disc, configures the MPLS, loads the data out of the MPLS buffer and creates the *.pri and *.bri files. If the probe is rotated (in order to prevent reflections in the disc grooves), the files have the ending *.bri.rot and *.pri.rot. If rotated files are loaded the first time into PRISM, the angle correction is done automatically and a new file without the ending *.rot is created so this repositioning of the points has to be done only one time.

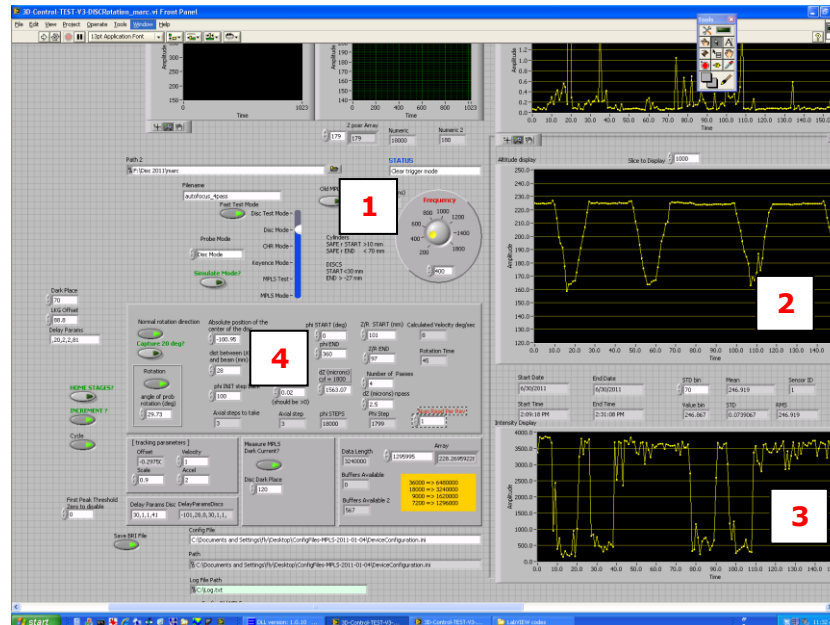


Fig. 27 - Disc scanning tool

- 1 Exposure time of the MPLS.
- 2 Plots the last from the MPLS received altitude data.
- 3 Plots the last from the MPLS received brilliance data.
- 4 Different mechanical parameters such as region of the disc to scan, rotation of the probe, number of passes etc.

2.5.6 Data distribution in multiple pass scans

By taking a single pass scan, the system only takes a data point every 10 microns. By performing a four pass scan this distance decreases to 2.5 microns and the number of points is increased by four. This allows distinguishing better the good from the bad data points. Taking a multiple pass scan, the LabView tool stores the points of the different passes automatically in the right order as shown in Fig. 28.

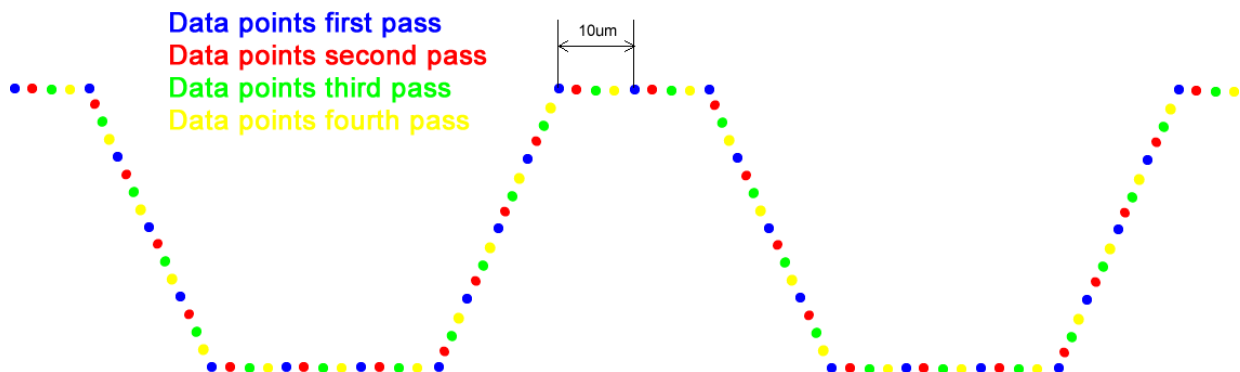


Fig. 28 - Data distribution in multi pass scan

2.5.7 Disc data processing – PRISM

Once the *.pri and *.bri files are created, the application PRISM can be used. Before opening a file, the parameters (#1 in Fig. 29) must be set. PRISM is used for processing cylinders and disc data, so first the user must specify the type of data. Then the parameters for the tracking and the algorithm to determine the center of every groove with its parameters must be set. Once all the parameters are programmed, the file can be loaded. If the file has the ending *.rot, PRISM automatically computes the points back to the place where they would be if the probe had not been rotated and saves this data in a new file. As soon as the file is loaded, the whole file is shown in the main window (#2 in Fig. 29). Clicking in this window, a zoom of the cursors' current position is shown in the right window (#3 in Fig. 29). By clicking in one of those two windows, PRISM plots the corresponding data points in the lower window (#4 in Fig. 29). By checking the option below this plot it is also possible to show the result of the fitting algorithm for each groove. Every time one of those parameters is changed, the file has to be reloaded; otherwise the changes will not be applied to the current data. If the grooves could not be tracked by auto tracking (bad setting of the parameters or bad condition of the disc), PRISM provides a manual tracking function where the user can track the grooves with the mouse.

Once the grooves are tracked and the fitting algorithm finds the center of every groove, the audio file can be produced and listened to in the implemented audio player (#5 in Fig. 29).

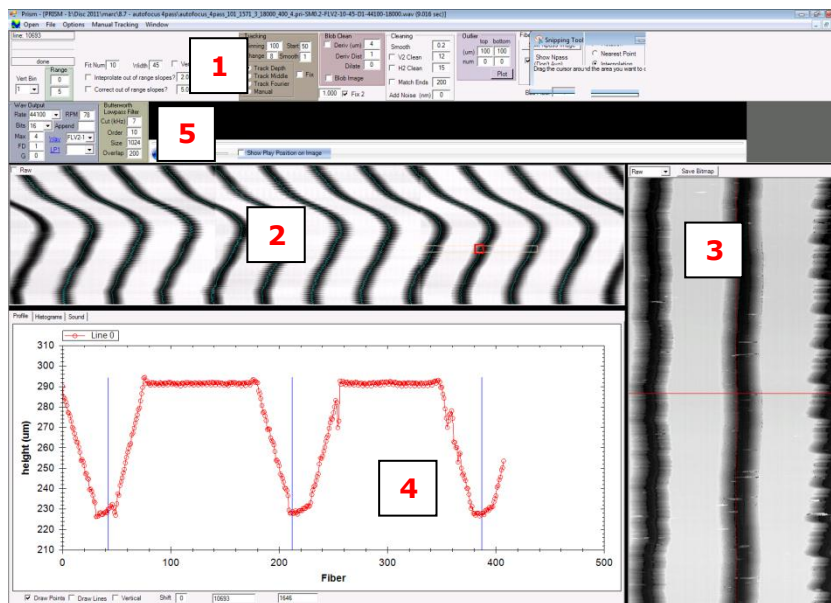


Fig. 29 - Disc data processing tool PRISM

- | | |
|---|--|
| 1 | Parameters for tracking and fitting. |
| 2 | Main window – shows the current data file. |
| 3 | Zoom window – shows a specified part of the data. |
| 4 | Shows the data points and fitting results of the corresponding area. |
| 5 | Wav file creation and audio player. |

3 Hardware part – data acquiring

All the analysis and developed tools for the hardware part of the project are documented in this chapter. The hardware part refers to everything related to the scanning process, motor stage control, distance sensor, etc. Those tools are developed in LabView.

3.1 General problem analysis

3.1.1 Z-offset in multiple pass scans

In order to get more data points (in order to throw away bad points), multi pass scans are performed. This means that the same region of the disc is scanned multiple times. By analyzing the data taken in multiple pass scans, offsets between the different passes are observed. With such data, the algorithms have difficulty detecting the center of the grooves and therefore the sound quality is bad.

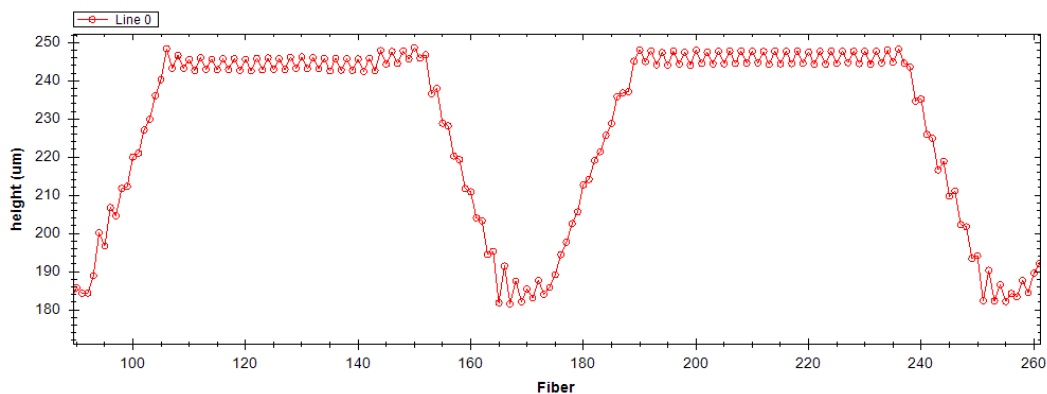


Fig. 30 – Measure of Z-offset between different passes in a two pass scan

One method to counteract this offset, PRISM simply takes the four points of the different passes and computes the average. This increases the sound quality, but a lot of information are getting lost that way and the sound quality is not much better than in a one pass scan.

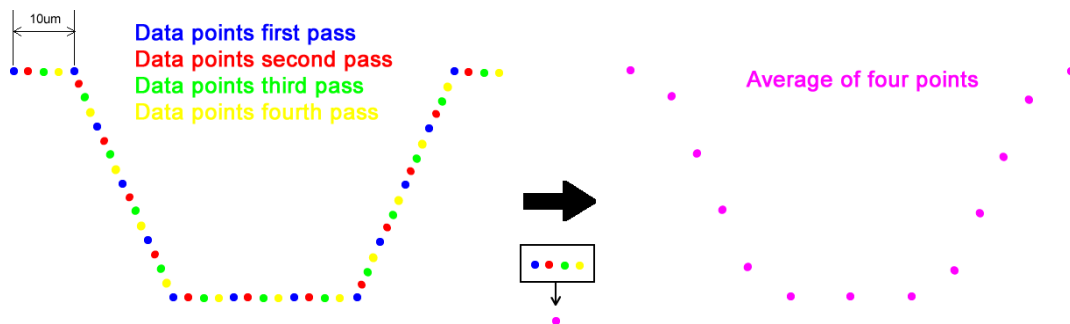


Fig. 31 - Multiple passes averaging

This offset can be caused from different sources. Either the disc is mechanical not stable on the platter due to accelerations and decelerations during the scanning process, the whole system moves due to temperature instability in the room or the laser based autofocusing system is not perfectly precise.

3.1.2 Focusing system

The MPLS has a very small range of 350 microns. Given that discs are not 100% flat but warped (Fig. 32), the shape of such discs can reach up to a couple of millimeters. This will cause problems if the probe always stays in the same position, because while turning the disc, it will move out of range of the MPLS. Therefore the height of the MPLS is adapted in real time while scanning. This duty is done by the laser distance sensor which constantly measures the current height of the disc on the platter. The system uses the analog output of this laser distance sensor which is connected to the XPS controller. The XPS contains a programmable “analog tracking” function which is used, to constantly keep the probe in range. This system, called auto focus, is currently used to adapt the height of the probe for disc and cylinder scanning. This system is easy to set up and works well for single pass scans. Unfortunately it was encountered, that if a multiple pass scan is performed, the auto focus does not always position the probe to the same height for each scan. As result the different passes have offsets between each other. This offset is in a range of around 2 to 4 microns.

A gramophone record observed from the side is not flat. Depending on the material and condition of the disc, its shape is more or less important.



Fig. 32 - Warped disc

Since the laser beam does not point to the same point on the disc that the probe is looking at, a delay is implemented to correct this angular offset.

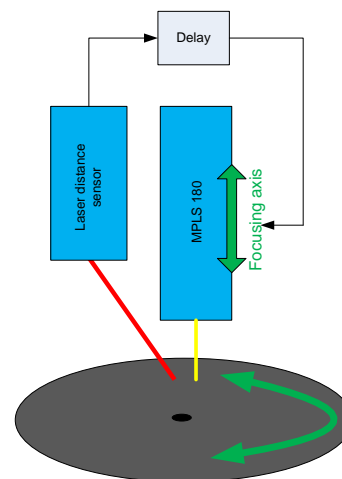


Fig. 33 - Autofocus

There are two main factors making the focusing system imprecise, first is the measurement of the distance by the Keyence laser distance sensor itself. The problem is that the surface of the disc is not flat, but full of edges. This causes reflections and makes it hard for the distance sensor to perform a precise measure. This was proved by logging the output of this distance sensor on specified points over multiple rotations and comparing them.

Another possible source of the focusing problem might be the backlash of the motor stage which adjusts the height of the probe.

The focus adjustment is performed by a Newport LTA-HS motion stage.



Fig. 34 - LTA-HS

Specifications

	LTA-HS
Travel (mm)	50
Resolution (μm)	0.035
Minimum Incremental Motion (μm)	0.1
Uni-directional Repeatability, Guaranteed ⁽¹⁾ (μm)	0.5
Bi-directional Repeatability, Guaranteed ^{(1),(2)} (μm)	
On-Axis Accuracy, Guaranteed ⁽¹⁾ (μm)	15 or ± 7.5
Maximum Speed (mm/s)	
Axial Load Capacity (+Cx) (N)	50

In attempt to avoid these problems, a new focusing strategy has been developed. The focusing data of the first pass is logged in a file, and used for the next three passes. Even if the measurement of the first pass is not perfectly correct, the same data will be used to adjust the probe in the next three passes and therefore the error should be exactly the same all four times. This should also correct the problem with the backlash of the motor, because the control commands for all positions in all passes will be sent in the same sequence and will contain the same position.

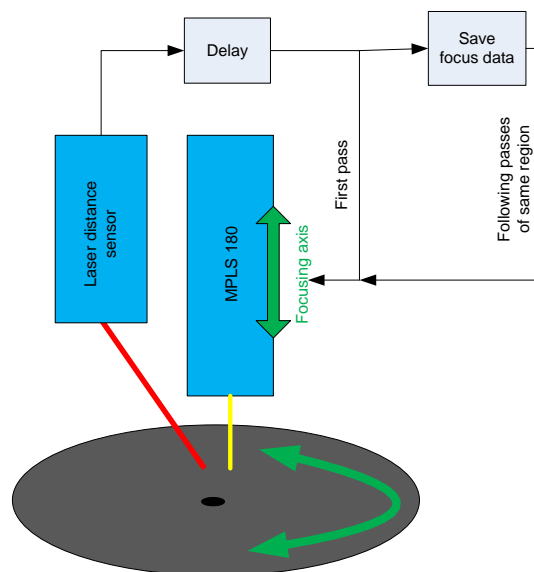


Fig. 35 - Focus data saving

3.2 Realizations

To test this focusing system, three different VI's (a VI is a LabView program) have been developed: one to save the data into a file (3D-Tools_GatherZ.vi), one to analyze the saved files (3D-Tools_compare.vi) and one to control the focusing stage using the file from the first tool (3D-Tools_focus_v8.vi). With these three tools, the new Focusing system was developed. Now the tools are only used to adjust the different parameters and for debugging purposes. All those tools were finally implemented in a single VI named "3D-Tools_scan.vi", so the user has not to deal with all these different VI's to scan a disc.

Additionally a tool named "3D-Tools_viewer.vi" was developed. This tool allows the user to look at the current data, adjust manually or automatically the start height of the focus and check if the focus is working when the disc is rotating. All the important parameters for all the tools are saved in "3D-Tools_global.vi".

3.2.1 Focus logging tool: 3D-Tools_GatherZ.vi

As explained in chapter 3.1.2, the disc scanning process for multi pass scans uses an autofocus system to keep the probe always in its range. To receive good data at the end of a multi pass scan, all the passes must be taken at exactly the same distance above the disc for every point.

3D-Tools_GatherZ.vi scans the shape of the disc (laser distance sensor data, not MPLS data!) and saves it into a file. These files can later be used in the 3D-Tools_compare.vi tool to compare different settings of the filter or laser distance sensor parameters, and of course in the "3D-Tools_focus_v8.vi" to adjust the height of the MPLS while the disc is rotating.

Different methods exist to log this distance sensor data. The XPS motion controller provides a function named "Data Gathering" which proved itself as a very good adapted method to perform this data logging. Three different methods of gathering such as external trigger, internal timing trigger and event trigger based gathering exists. Data Gathering is an automatized data logging processes which will save up to three defined variables (for example motion stage positions or analog inputs) on every trigger event into a data file. In this case, the data logging is controlled by external trigger based gathering. The trigger source is the encoder of the rotating stage which is programmed to produce an impulsation in a defined spacing (default value is set to 0.45°). Then the disc simply rotating for a defined number of rotations and the value of the specified variables are automatically saved by the XPS on every arriving trigger flank. Once all the data is taken, the XPS creates a file "GatheringExternal.dat" which can be downloaded by FTP.

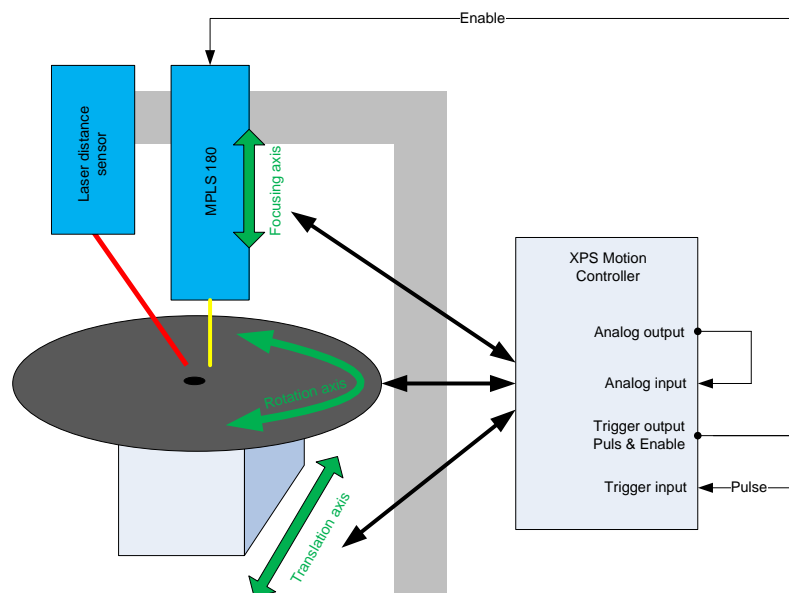


Fig. 36 - XPS cabling

To make this tool work, the cabling of the XPS need to be changed. The trigger out connector contains two signals, trigger enable and trigger pluses, a stabilized 5V tension and a ground. The enable signal goes as it was before to the MPLS and the pulse signal goes back into the XPS trigger input. The trigger outputs are open collector outputs. To distribute the trigger signal to its destination, a Y-cable with 470Ω pull-up resistors to the 5V tension has been realized.

Additionally Fig. 36 shows the connection from the Analog output back to the analog input. This connection is used for all the analog tracking functions of the focusing stage (gathering or MPLS focus).

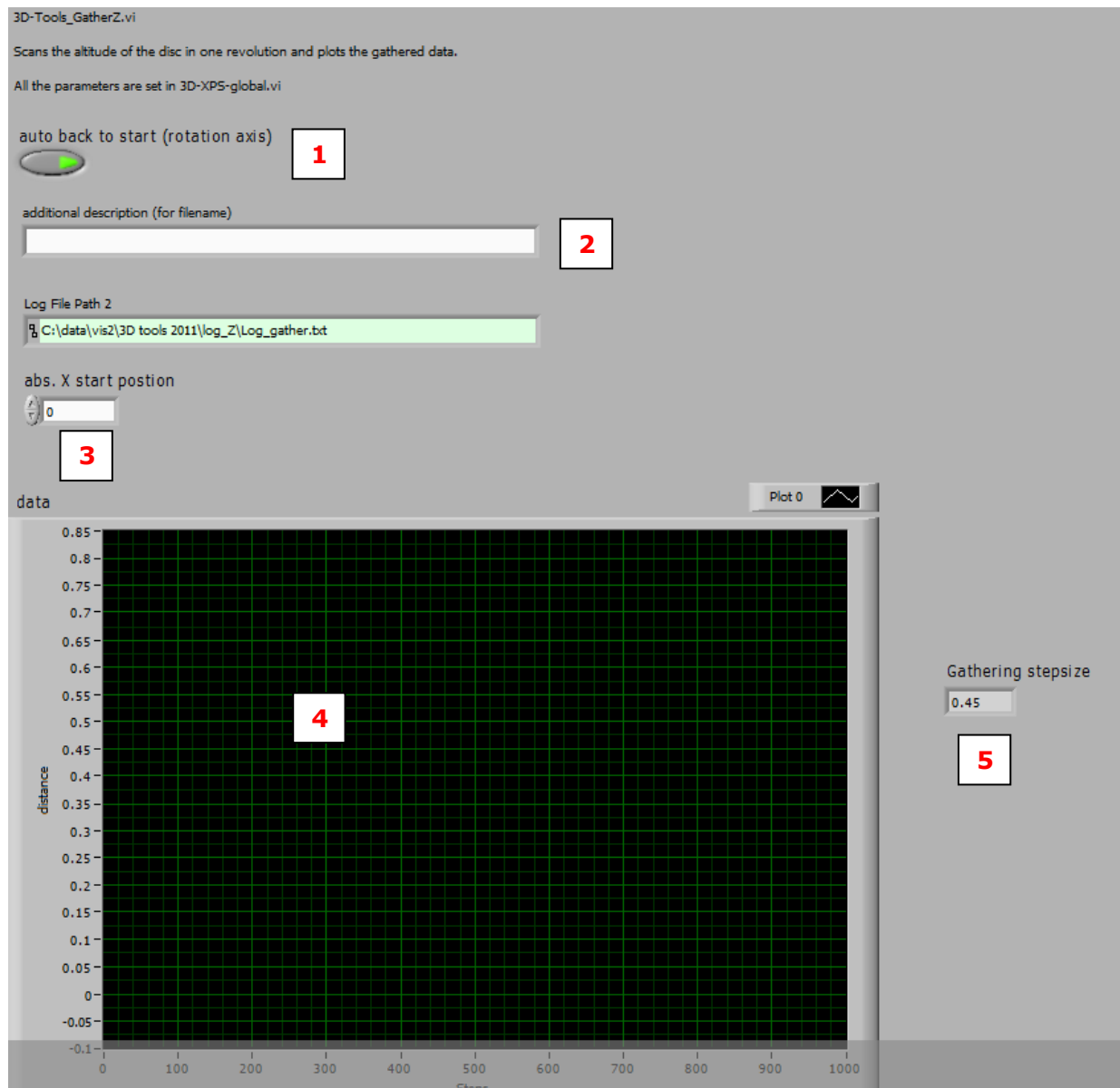


Fig. 37 - 3D-Tools_GatherZ.vi

- 1 If true, the rotation stage goes back to 0° after the data gathering.
- 2 Additional description of the measure which will be added to the filename.
- 3 Absolute X start position of the measurement.
- 4 Plots the gathered data once the scan is complete.
- 5 Shows the step size of the data gathering (can be adjusted in the global).

Once the scan is done, 3D-Tools_GatherZ.vi saves the file with the acquired data in the chosen folder. The file is in a *.dat format and contains simply three columns with the acquired data.

Example of a GatheringExternal.dat file:

0.0002	0	0
GROUP1.POSITIONER.ExternalLatchPosition	GPIO2.ADC1	GROUP3.POSITIONER.ExternalLatchPosition
-45	-0.04994146033597	4.96835243854
-44.955	-0.04994146033597	4.96835243854
-44.91	-0.05239257495369	4.96835243854
-44.865	-0.05239257495369	4.96835243854
-44.82	-0.05239257495369	4.96835243854
-44.775	-0.05239257495369	4.96835243854

To simplify the use of those files, all the important parameters of the scan are implemented in its filename.

Example of a filename:

6_27_2011__5-27-49PM__focus_data__rot_1__stsz_0.04__trigStart_-45__velo_10__acc_10.dat

Explication:

Date – Time – File title – Number of revolutions – Step Size – Point where the trigger starts – Velocity(of the rotation stage) – Acceleration(of the rotations stage).dat

3.2.2 Tool to analyze the gathering files: 3D-Tools_compare.vi

To be able to analyze the gathered data of the disc surface, a LabView tool has been created. The input of this tool is the gathering files which are explained in chapter 3.2.1. Once such a file is loaded, the tool displays different plots of the data.

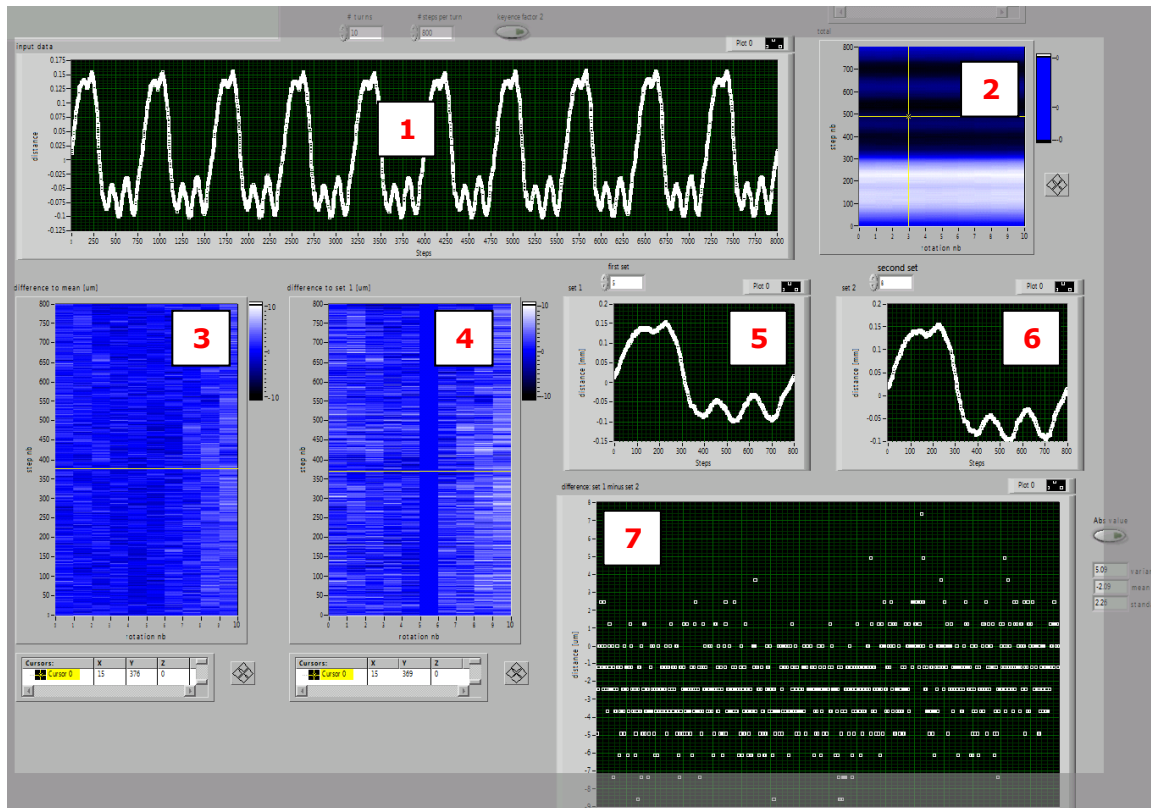


Fig. 38 - 3D-Tools_compare.vi

- 1 Shows all the data points which the loaded file contains.
- 2 Same data as plot one with a colored 3D plot.
- 3 Computes the mean of the overall shape and calculates the difference.
- 4 Shows the difference to the selected X dataset.
- 5 Single rotation X of the whole dataset can be shown here.
- 6 Single rotation Y of the whole dataset can be shown here.
- 7 Shows the difference between datasets X and Y.

This tool is useful to observe the laser distance data over longer periods of time. The 3D-Tools_GatherZ.vi is plotting the gathered data as well, but if more than one rotation is measured, this plot shows fewer details. Problems as instability of temperature and so on can be analyzed well with 3D-Tools_compare.vi.

3.2.3 Z-axis control: 3D-Tools_focus_v8.vi

The most important tool to test the focusing system is 3D-Tools_focus_v8.vi. This tool takes as input a gathering file which is created by 3D-Tools_GatherZ.vi (chapter 3.2.1). The loaded data taken by the laser distance sensor is filtered, shifted, scaled, and finally used as a distance parameter to adjust the height of the focusing stage motor. Both datasets, the raw data and the final repositioning data which is used to adapt the height of the MPLS, are plotted on in two different graphs. The first plot with the raw data shows 45° of data more at the beginning and at the end. This additional data is taken to prevent the data from having errors due to the initial conditions of the filters. Once the filtering is done, this additional data will be cut off.

The positioning of the Z-axis is finally done by analog tracking. This means that 3D-Tools_focus_v8.vi is not sending position commands to the motion stage, but it is setting the Z-axis into analog tracking of a bridged analog output (Fig. 36). Then the program has simply to adjust the analog output voltage. Advantage of this method is that the voltage setting command is much faster than the repositioning command (because the reposition command goes into blocking mode until the final position is reached). Using this method, the focus can be adjusted in a faster and more efficient way.

All the important parameters to make the focus work can be settled inside this tool (and not in the global as it is the case for most of the other VI's.) This makes it easier for the user to "play around" with these parameters to find the optimal values. Once the parameters are settled to a good value, the user must save these values manually into the global. This is because the scanning tool provides exactly the same filters, but it is taking the parameters out of the global.

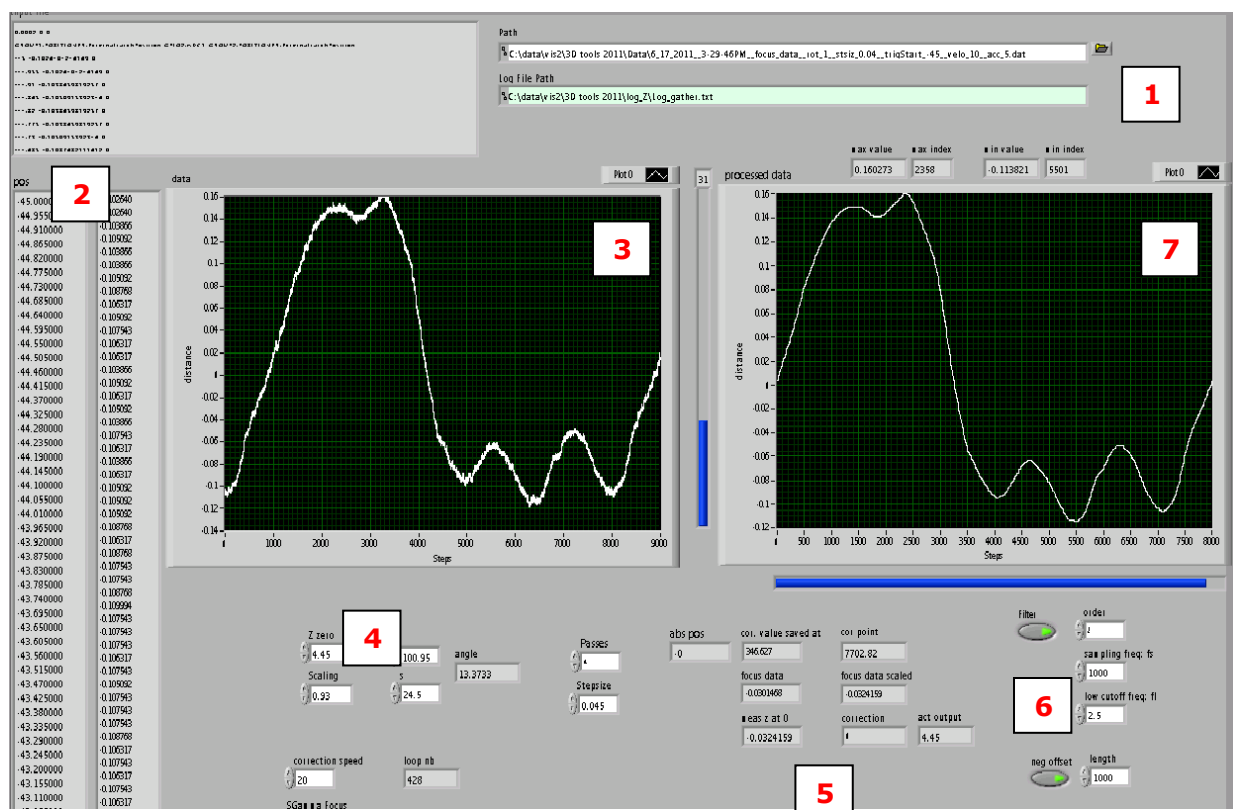


Fig. 39 - 3D-Tools_focus_v8.vi

- 1 Path of the gathering file.
- 2 Shows the loaded data.
- 3 Shows the shape of the loaded data.
- 4 Hardware parameters (Z-zero offset, angle between laser and probe, distance to center)
- 5 Gives information about the current correction.
- 6 Filter parameters.
- 7 Filtered data.

Mechanical parameters

The functionality of the focusing tool depends strongly on the entered parameters. Two mechanical parameters have to be set in the program. In addition, different settings on the filter and the adjusting speed can be made by the user.

Data angle offset

An offset angle is implemented because for a given angle of the rotating system, the distance sensor and the MPLS are not measuring the same place of the disc.

$$\alpha = \tan^{-1}\left(\frac{24}{d}\right)$$

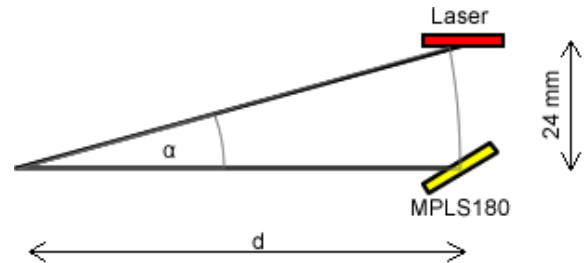


Fig. 40 - Angle between MPLS and laser

Scaling factor

The laser distance sensor is not mounted vertically over the disc. So if the laser distance sensor detects a certain movement, the height of the MPLS will not be corrected exactly to that same value. A scaling factor is implemented to correct this default.

$$a = \sin^{-1}\left(\frac{90 - 24}{160}\right) = 24.3^\circ$$

$$\text{scaling factor} = \cos(a) = 0.911$$

To check this factor, the height of the probe of different heights and its corresponding laser distance sensor values were measured.

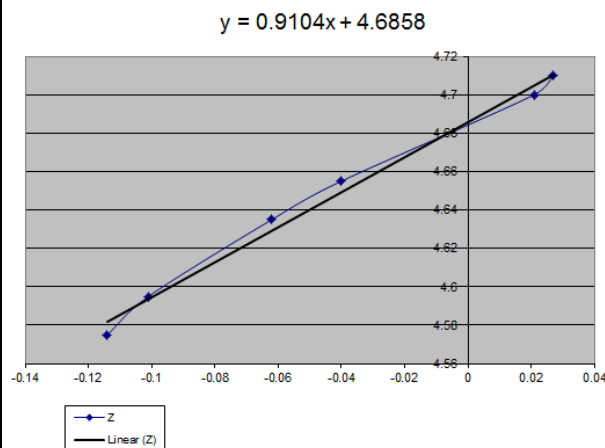


Fig. 41 - Scaling factor measure

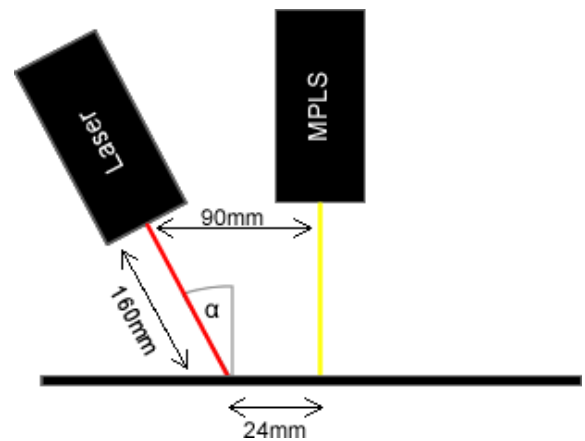


Fig. 42 - Scaling factor

The implementation of the scaling factor is the inverse of this value. So the default parameter is $\frac{1}{0.911} = 1.1$

3.2.4 MPLS Focus

During the project a new method to adjust the height of the probe was developed. Instead of using the laser distance sensor to adjust the height, the data taken by the probe itself could be used. Therefore the data is read out of the MPLS multiple times per rotation. Before the data was only once per rotation read. Reading this data for example thousand times per rotation allows analyzing the data already during the scanning process.

Two parameters are available to configure this focusing method. First is the upper level of the sound carrier where the MPLS should be adjusted to and second is the method which is used to compute the upper level.



Fig. 43 - MPLS focus

- 1 Desired upper height level of the disc.
- 2 Method to compute the height.
- 3 Measure of the current height computed with the in 2 selected method.

Similar as for the gathering focus, the motion stage is controlled by analog tracking. A PID computes the difference between measured and desired value and corrects the analog voltage which will, since the focusing stage is in analog tracking mode, move this stage.

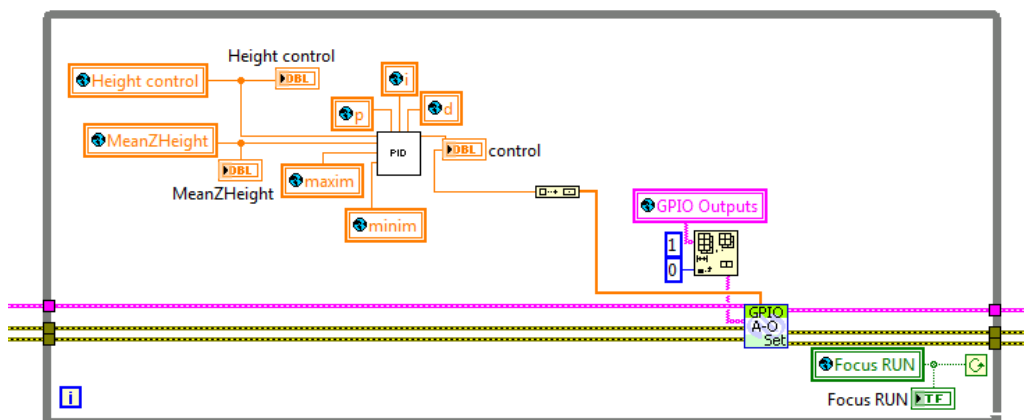


Fig. 44 - 3D-Tools_adjustFocus.vi - Block diagram

3.2.5 3D-Tools_viewer.vi

At the beginning 3D-Tools_viewer.vi was only used to watch the current data of the MPLS. In fact 3D-Tools_viewer.vi was a replacement for the LinesensorExample.exe: a tool form which is delivered with the MPLS and shows the altitude and the brilliance of the 180 points (Fig. 17 - 3D scanning data Fig. 17). It was developed because LinesensorExample.exe did not work under Windows7 and because it will probably not work with a 64bit environment. With 3D-Tools_viewer.vi, the user is no longer depended of this tool.

During the project, different features were added to 3D-Tools_viewer.vi which makes it now to a very useful tool.

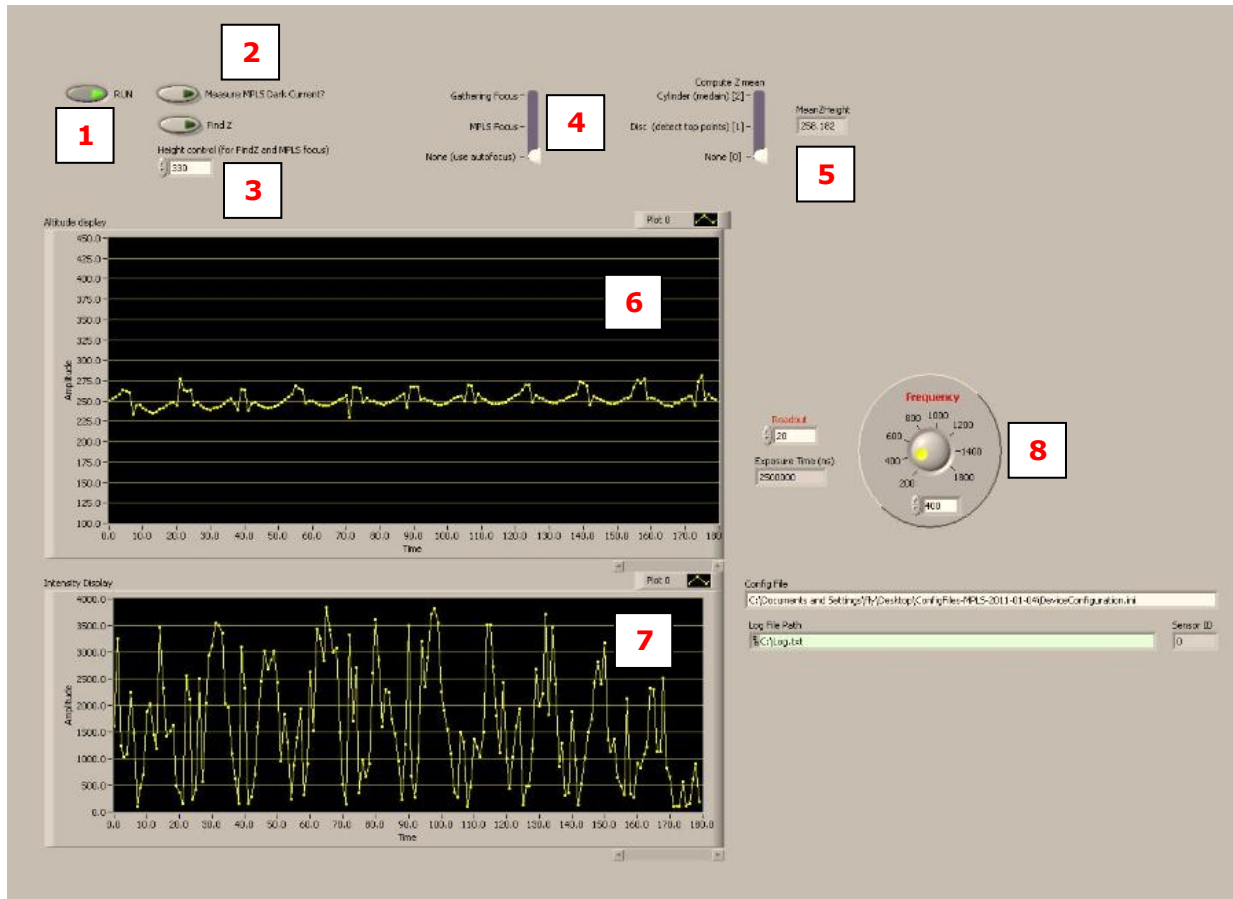


Fig. 45 - 3D-Tools_viewer.vi

- 1 The VI must be stopped by pressing the RUN button. This is because the program runs in a loop. If the Vi is stopped with the LabView stop button, the connections to the devices (MPLS and XPS) are not disconnected and the program will crash on the next start.
- 2 Performs a dark current measurement. This is necessary if the frequency of the MPLS has been changed.
- 3 FindZ adjusts the MPLS automatically to a good start height that the user does not have to find it manually.
- 4 3D-Tools provides three different focusing methods: Autofocus (this method consists of delaying the laser distance data and using that data as tracking parameter), Gathering Focus (the method which saves the focusing data into a file, applies filters and uses the same data for different passes), and MPLS focus (which uses the data of the MPLS itself, tries to find the upper level of the sound carrier (with the "Compute Z mean" function) and adjusts the probe to an optimal height. All these methods can be activated in the viewer in order to check if the chosen method will work with the current disc before starting the scan.
- 5 "Compute Z mean" tries to find the upper level of the sound carrier. Two different methods are available. One for discs and one for cylinders. The disc method tries to find the points with high energy (which are supposed as the points on the upper side of the disc) and fits a line through them. The cylinder method takes simply the median of the altitude data, which works not so bade since the grooves are not very deep. Those two functions should be improved in feature to make the whole system work in a proper manner.
- 6 Plot of the altitude data.
- 7 Plot of the brilliance data.
- 8 Scanning frequency of the MPLS.

3.2.6 3D-Tools_global.vi

All the important parameters such as mechanical parameters, data paths, IP addresses, regulator and filter parameters for all the different VI's as stored in this VI



The screenshot displays the 3D-Tools_global.vi interface, which is organized into several functional panels:

- Positioner and group names (1):** A list of motion stages and their corresponding group names, including RS1500 Rotation GROUP, RS1500 POS, RS1500 Translation GROUP, RS1500 POS, LTA-HL Focus GROUP, LTA-HL Focus POS, RS1500BL Cylinder GROUP, RS1500BL POS, XM 200 Cylinder Lower GROUP, XM 200 POS, LTA-HS MPLS Cylinder GROUP, LTA-HS MPLS Cyl POS, LTA-HS MPLS Disc GROUP, LTA-HS MPLS Disc POS, and their respective POSITIONER names.
- XPS connection (2):** Fields for IP Address (128.3.125.249), Connection ID in connection TOP, Log File return, and Log To File.
- Tracking Position Parameters MPLS Focus (4):** Parameters for tracking the MPLS focus, including SFO Name (AD), Offset (Volts), Scale, Velocity (units/s), Acceleration (units/s²), and various limits.
- Analog I/Os (3):** Fields for GPDO Outputs (GPDO2.DAC1, GPDO2.DAC2, GPDO2.DAC3, GPDO2.DAC4) and GPDO Names (Analog) (GPDO.ADC1, GPDO.ADC2, GPDO.ADC3, GPDO.ADC4).
- Gathering Focus (5):** Parameters for the gathering focus, including NPLS Focus, Mean Zheight, Auto Focus, and Auto Focus.
- Gathering Focus (6):** Parameters for the gathering focus, including laser - MPLS offset angle, correction speed, scaling, filter type, order, sampling freq, filter structure, and low cutoff freq. It also includes two plots: 'unfiltered' and 'filtered' showing distance vs. steps.
- Data Gathering (7):** Parameters for data gathering, including User, Password, File Name to Get, Event trigger set, Action Name, # points, Para 2, and a list of gathering type units.
- Tracking Position Parameters Gath Focus:** Parameters for tracking the gathering focus, including SFO Name (AD), Offset (Volts), Scale, Velocity (units/s), Acceleration (units/s²), and various limits.
- Position Compare Parameters Gathering:** Parameters for position comparison, including Minimum Position, Maximum Position, and Position Step.
- Science Parameters Rotation Gathering:** Parameters for rotation gathering, including Velocity (units/seconds), Acceleration (units/seconds²), Minimum Jerk Time (seconds), and Maximum Jerk Time (seconds).
- Science Parameters Rotation Back Gathering:** Parameters for rotation back gathering, including Velocity (units/seconds), Acceleration (units/seconds²), Minimum Jerk Time (seconds), and Maximum Jerk Time (seconds).
- Science Gathering Focus Stage:** Parameters for focus stage gathering, including Velocity (units/seconds), Acceleration (units/seconds²), Minimum Jerk Time (seconds), and Maximum Jerk Time (seconds).

Fig. 46 - 3D-Tools_global.vi

- 1 Positioner and group names for all the motion stages which will be used.
- 2 XPS connection parameters.
- 3 Names of the analog I/O's of the XPS.
- 4 Tracking and regulator parameters for the MPLS focus.
- 5 Current focus setup and upper/lower level. (Used to communicate between different VI's).
- 6 Parameters and plots for the gathering function.
- 7 Parameters for the data gathering. (FTP login, gathering steps and limits.)

3.2.7 3D-Tools_scan.vi

Once all the parameters are set and the focus is assumed as functional, the scanning tool can be started. Besides of the changes of some cleaning up of old functions and the implementation of the new focus, this tool remained the same as at the beginning of the project described in chapter 2.5.5.

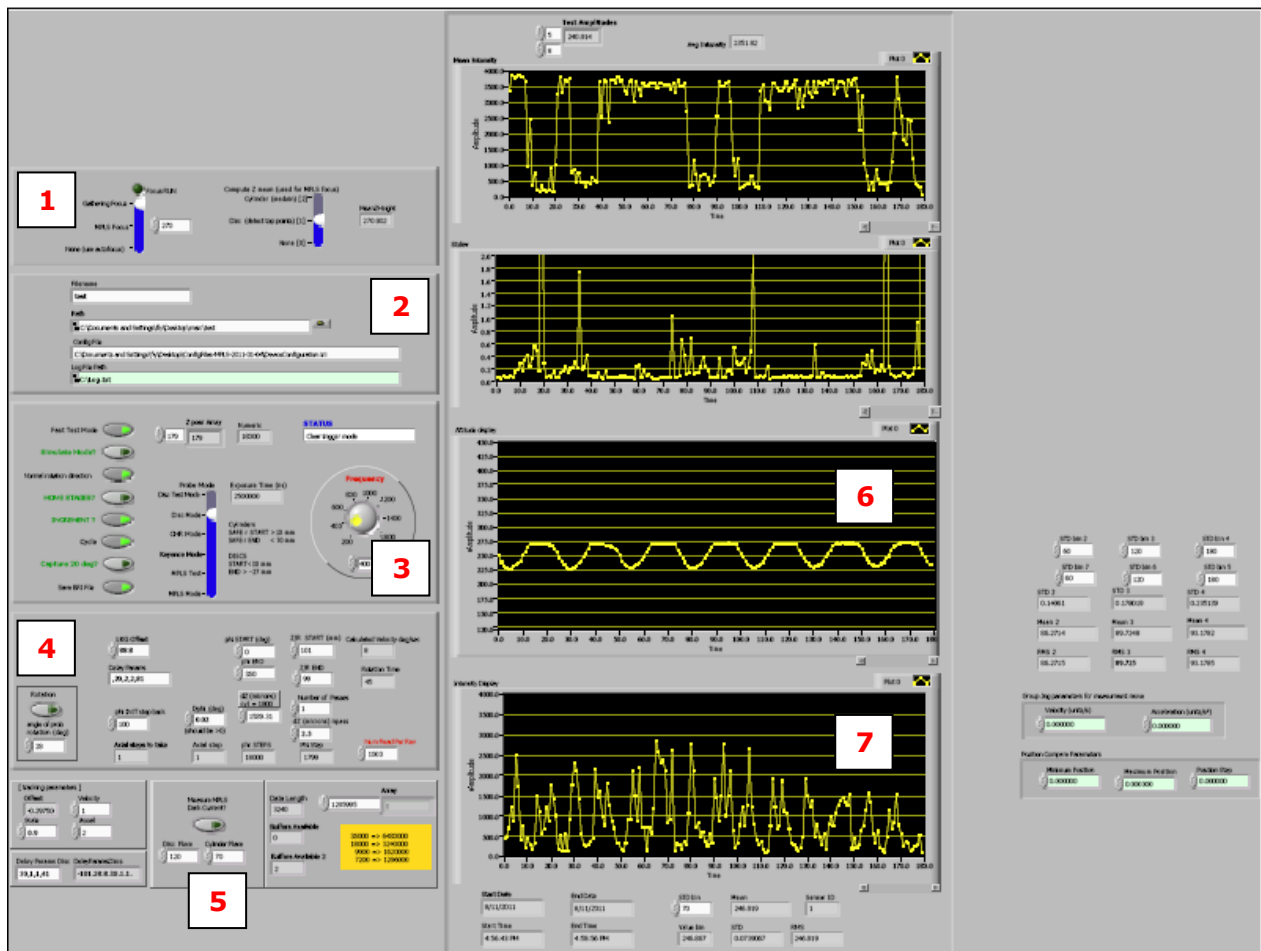


Fig. 47 - 3D-Tools_scan.vi

- 1 The three available focusing methods can be selected here. If MPLS focus is selected, a height detection method and the corresponding height value must be entered. If the autofocus method is selected, the user has to put the z-stage manually into analog tracking mode, as it was the case before the implementation of the new focusing tools.
- 2 Selection of the folder and filename where the acquired data will be saved.
- 3 Scanning mode and MPLS setups.
- 4 Different mechanical parameters such as region of the disc to scan, rotation of the probe, number of passes etc.
- 5 Dark measurement (necessary if the exposer time of the MPLS has been changed).
- 6 Plots the last from the MPLS received altitude data.
- 7 Plots the last from the MPLS received brilliance data.

3.2.8 Sub VI's

In order to keep the VI's simpler to understand and adapt, different subVI's were developed. The user does not need to adapt any parameters in these VI's. Every VI is reading its parameters in 3D-Tools_global.vi.

set-trig.vi	Activates the pulse compare output of the rotation stage. This pulse is used to trigger the data gathering.
set-gathering.vi	Activates the external trigger based data gathering.
timestamp.vi	Collects all the parameters of the last data gathering and produces a filename. This VI's is used in get-ftp.vi.
get-ftp.vi	Loads the last gathering data file out of the XPS and saves it to a specified path on the computer.
Zheight.vi	Zheight tries to find the upper level of the sound carrier. Two different methods are available. One takes the upper points of the disc and fits a line and the other simply takes the median of all the altitude measures (works for cylinder data).
setStart.vi	This VI is used for the findZ function of 3D-Tools_viewer.vi. It moves the probe back down to zero and moves It then slowly up until the function Zheight detects the sound carrier on a good level.
setFocus.vi	SetFocus.vi set at the beginning of 3D-Tools_scan.vi or 3D-Tools_viewer.vi the focus in the chosen mode.
adjustFocus.vi	See chapter 0 – MPLS focus.
pid.vi	Pid.vi is a PID regulator which is used for the MPLS focus.

3.3 How to scan a disc

This chapter explains the most important steps to scan a disc.

1. What focus will be used?

Gathering Focus (continue at number 2)

- Discs with discontinuities (cracks).
- If the Zmean height algorithm is not able to compute the upper level (can be checked with the viewer tool), the gathering focus must be used.

MPLS Focus (continue at number 5)

- No big discontinuities.
- If the laser distance sensor is not able to measure the surface of the sound carrier in a good way, MPLD focus should be used.

2. Start the 3D-Tools_GatherZ.vi. Running it will scan one rotation of the disc and plot the acquired shape (laser distance sensor data). If the data looks good, the scan can be started.

If the data contains bad points, the scanning parameters of the laser distance sensor can be adapted.

Therefore the tool "LK-Navigator" (Fig. 48) must be started.

This tool allows doing an auto tuning or a manual adaptation of the parameters. For example different presets for different surfaces such as transparent, half transparent, multiple reflections are available.

Adapting these settings for different kinds of disc usually improves the measure in a very good manner.

Once the adaptations were made, the 3D-Tools_GatherZ.vi tool should be run again to see if the measure is better. If yes the scan can be started. If it is not possible to adjust the laser distance sensor, the MPLS focus can be used. (See number 5).

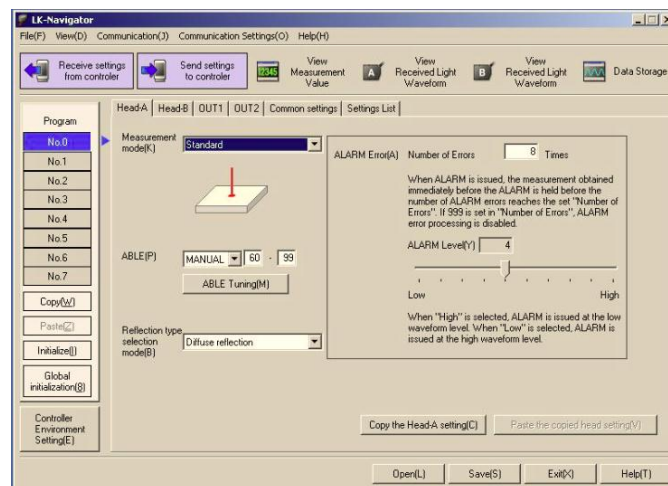


Fig. 48 - LK-Navigator

3. Once the 3D-Tools_GatherZ.vi tool shows good data (none or not much bad points), the 3D-Tools_viewer.vi can be started. The only thing to do here is to put the MPLS in a good height to start. Therefore the rotation stage must be moved to 0°. Then the height can be adapted either manually with the "Eye-program" (Fig. 49) or with the FindZ function which is implemented in 3D-Tools_viewer.vi.

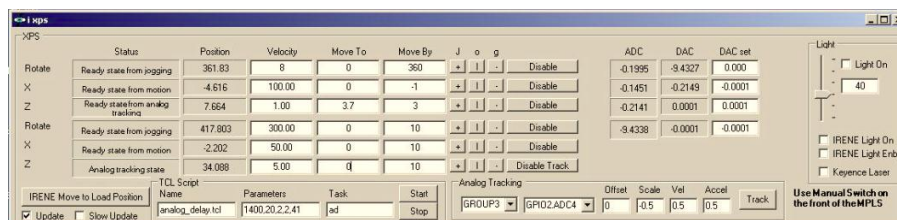


Fig. 49 - Eye program

4. If the start height is set (a good value is for example if the upper level of the disc is around 230microns), the 3D-Tools_scan.vi can be started. The focus must be set into "Gathering Focus" and all the mechanical parameter has to be set. Then the scan can be started.
5. If the laser distance sensor is not able to measure the surface of the disc, the MPLS focus can be used. Therefore the 3D-Tools_viewer.vi must be started and set into MPLD focus. By rotating the disc the correct tracking of the focus can be tested. If the disc has big discontinuities like cracks or deep scratches, this mode will probably not work. If the tracking works properly, 3D-Tools_viewer.vi can be closed and 3D-Tools_scan.vi can be started. Then the focus must set to MPLS focus and the scan can be started.

Encountered problems:

- 3D-Tools_scan.vi crashes at the start
Make sure that the analog tracking was turned off (use the eye program) and deactivate manually the positioner compare mode of the rotation stage. Therefore log in to the XPS terminal (with the web browser), go into terminal mode and execute the function PositionerPositionCompareDisable.
- Find Z is not working
Do a dark measurement.
Is a Z height modus selected?
Turn off findZ & focus, put the probe manually in range, start a compute z height modus and check if it is computing the right value. If not, the algorithm must be adapted for that type of disc.

3.4 Measures, tests and further development

Different measures and tests were made using the new tools which are described in chapter 3.2.

3.4.1 Test of the gathering focus

To check the functionality of the gathering focus, the movement of the focusing stage was saved during a rotation. The blue line shows the shape of the disc (measured with the laser distance sensor). The red line shows the position of the focusing stage while the disc is rotating and the Focus tool is running. To be able to compare the two datasets, the scaling factor was set to 1 for this measurement. This data was taken with the LogZ.vi tool.

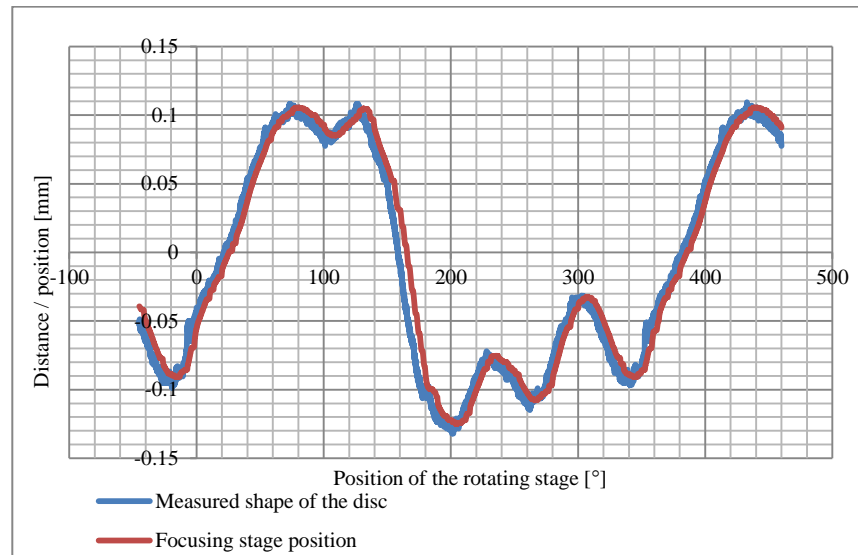


Fig. 50 - Gathering controlled focus

Comparing the red line with the blue one, some offset and phase shift are visible. The offset is a parameter in the Focus.vi tool which was not perfectly adjusted for this measurement. The visible phase shift corresponds to the phase shift of the filter, which is used to smooth the focusing data. This defect is corrected in the last version of the focusing tool. Therefore the fundamental functionality of the gathering focus works appropriately.

By analyzing the data taken with the new focus different results were discovered. On some places the data of the different passes matches perfectly together as shown in Fig. 51. This becomes best visible by observing the data points on the upper level of the groove. All the points are aligned on the same height.

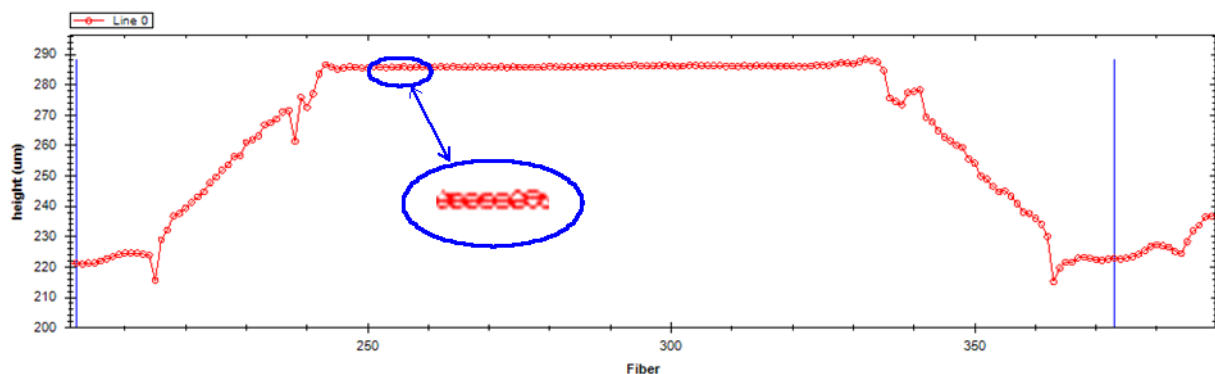


Fig. 51 - Gathering controlled focus, good example

On other places, the data of the different passes are not perfectly aligned. Fig. 52 shows data points out of the same file as Fig. 51, however it is visible that the top points in the second figure are not as good aligned as in the first figure. A repeating pattern of always four points appears over all data points. This correspond to the four passes of the scan which were taken from a slightly different height.

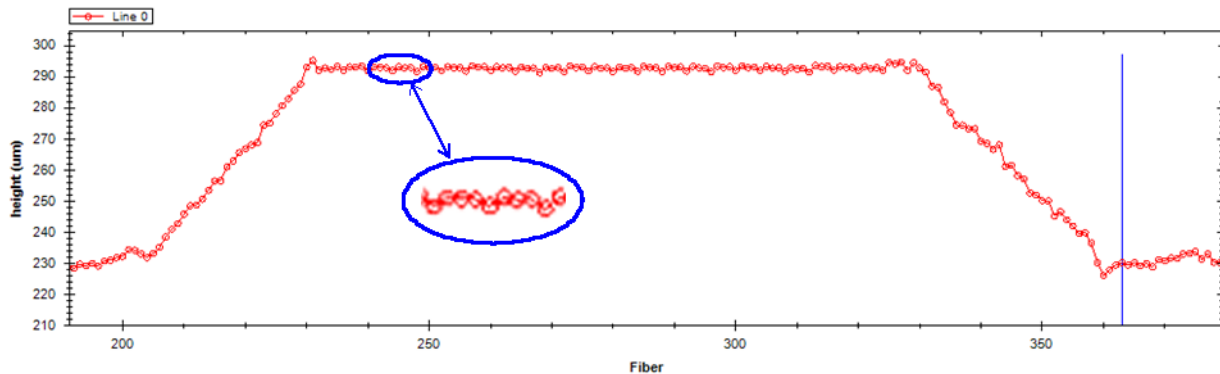


Fig. 52 - Gathering controlled focus, bad example

So on some places the data matches almost perfect. This is the case if the disc is very flat and therefore not much corrections of the height are made. On some parts of the data one of the passes is different from the others, on other places two of the passes matches and two are different and there are also places where the data points are distributed the same way as with the autofocus system.

Those differences can be caused by different sources. Usually velocity to scan the disc is about 8° per second. Therefore it takes around 45 seconds to scan one revolution. Then the system spins the disc back and restarts for the second pass. The passing time between different passes is also about 90 seconds. From the start of the scanning of one rotation in a four pass scan to its end, it takes around 6 minutes. During this time span, the disc is accelerated and decelerated several times. Additionally, the temperature will not remain stable during this time (see chapter 3.4.3). Those and maybe additional other factors are causing this offset.

3.4.2 Test of the MPLS Focus

The MPLS focus is a good tool to track disc without big discontinuities. If the sound carrier is warped, MPLS focus is working as well, but for example cracks are causing problems. This is because if the sound carrier goes out of range between two adjustments points (typically 0.36°), the tracking function does not know if the probe should be adjusted up or down.

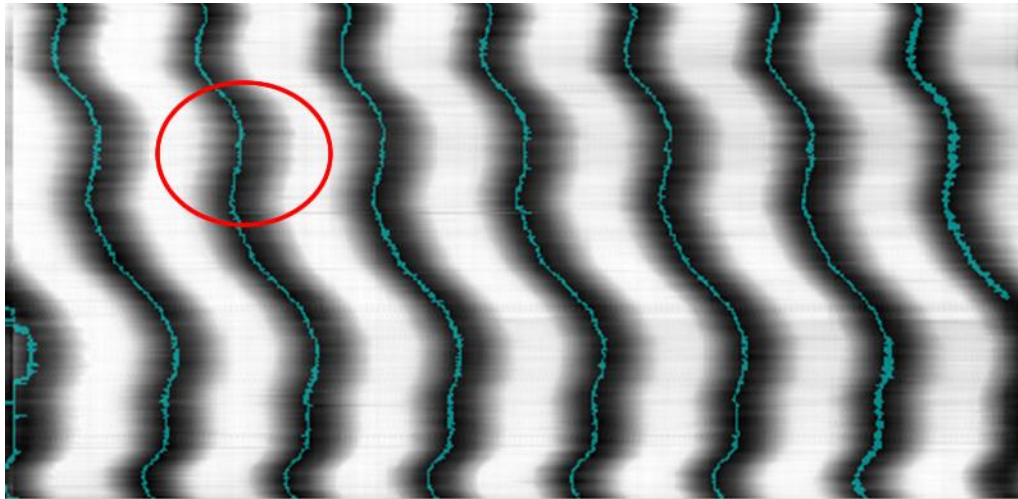


Fig. 53 - MPLS focus data

The data of the MPLS focus is good. Fig. 53 shows data taken with MPLS focus. The blue line is the tracking of the groove. The color is the height – the darker it is the deeper the data point is. On some parts (see red circle) it looks like as the whole groove is going up and down. This is an oscillation of the focusing stage around the ideal level produced by the PID regulator.

Fig. 54 represents one data part of the previous figure. It is a four pass scan and the MatchPass function is turned off. As visible in the blue circle the points contains almost no offset.

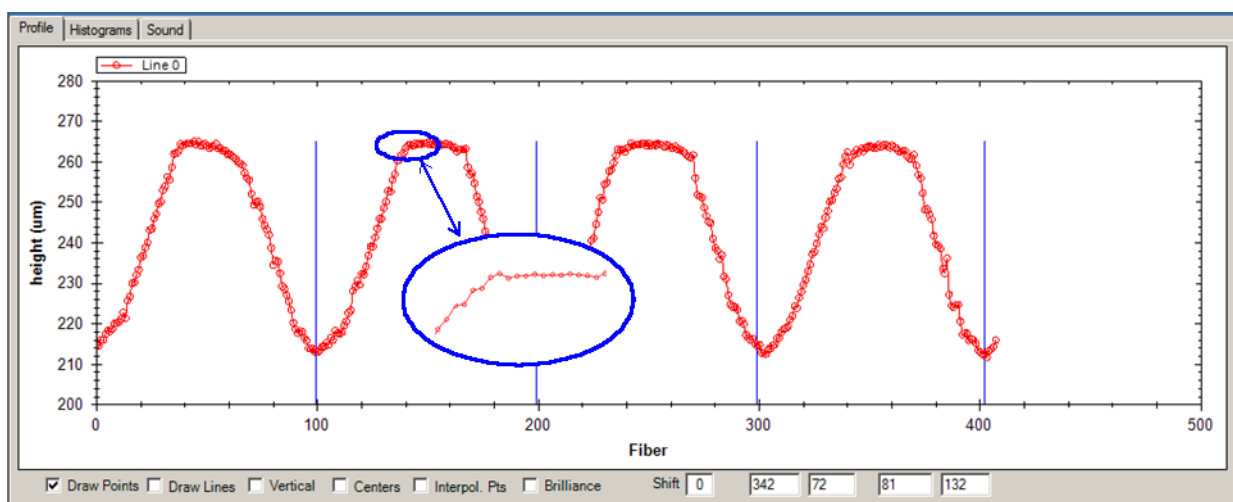


Fig. 54 - Data points MPLS focus

3.4.3 Dependence of external factors - room temperature

In order to analyze the behavior of the laser distance sensor respective the stability of the disc over longer time periods and different accelerations, different data measures over more than a single rotation were taken. These measures were made with 3D-Tools_GatherZ.vi and 3D-Tools_compare.vi (chapter 3.2.1 and 3.2.2). Analyzing the measured data (Fig. 55), a relatively interesting movement could be encountered. After a certain time, the measured mean distance of the laser sensor changed to a large value of roughly 10 microns.

Measure 1: 40 rotations in constant velocity in a time period of 24 minutes

Filename: 6_17_2011__2-10-46PM__focus_data__rot_40__stsz_0.45__trigStart_0__velo_10__acc_5.dat

(The filename of the measure contains information about the different parameters of the measure. Explanations for that are in chapter 3.2.1.)

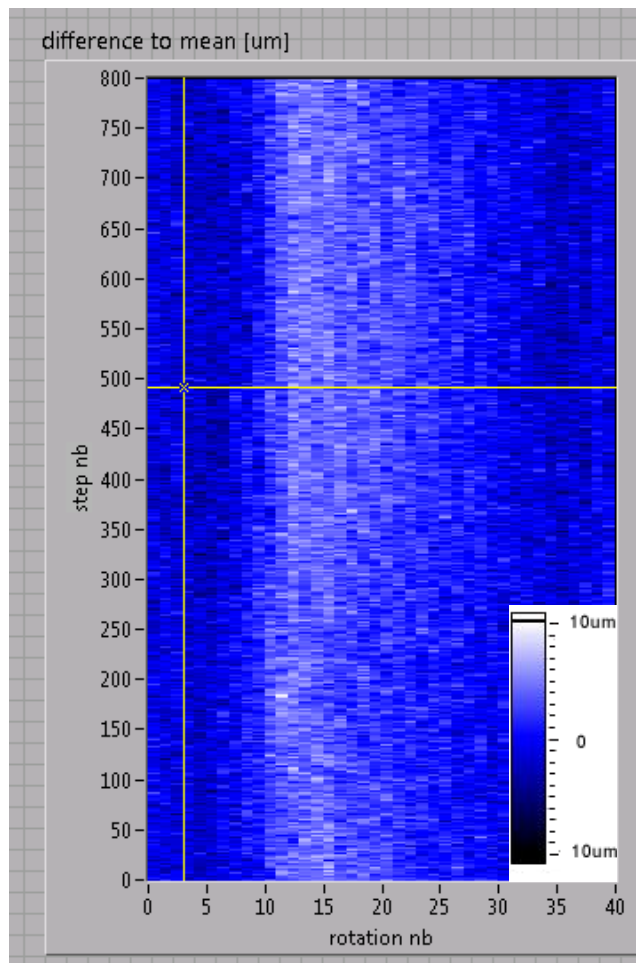


Fig. 55 – difference to mean with auto AC

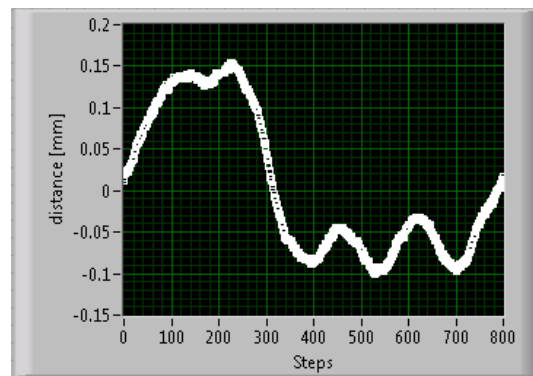


Fig. 56 - shape of the disc

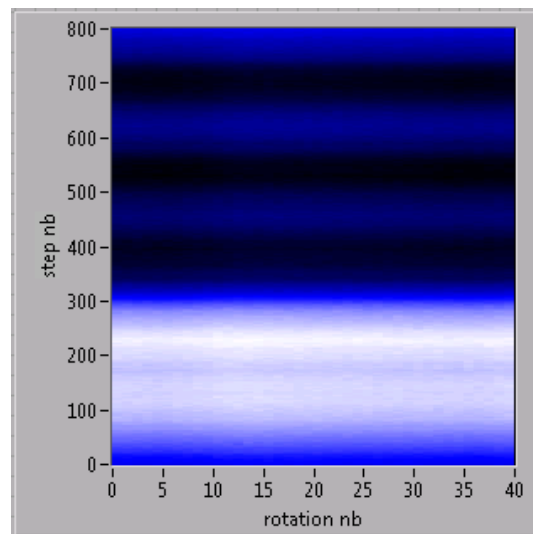


Fig. 57 - Overall plot with auto AC

Fig. 57 shows the measured shape of the disc (mean value over all the 40 passes). Fig. 57 shows the whole measured height data. The X-axis is the number of steps which corresponds to the angle of the disc ($360^\circ / 0.45^\circ$ per step = 800 steps) and the color is the height of every data point. Fig. 55 is the same data than Fig. 57, but the difference to the mean value is subtracted in every pass. By doing this, small differences between the passes become better visible.

After the 10th rotation, an interesting movement could be observed. The whole disc seems to move up a constant value of roughly 10 microns. The source of this movement must be an external factor. In the lab are two factors which could cause such problems. First the illumination of the room turns automatically off, if there is no movement in the room. The change of the environment light could slightly change the response of the laser distance sensor, but this would probably be a faster change. However Fig. 55 shows more a slow change of the height.

Second extern factor which could cause this movement is the instability of the room temperature (5 continuous running computers and other electronic devices heating up, and an air-conditioner cooling down). The air-conditioner has a thermostat, so it always tries to keep a defined temperature. Unfortunately this is not very stable.

After some observations, the air conditioner has been encountered as source of this problem.

To prove that this movement is caused by the instability of the temperature two similar measures were taken, one where the air-conditioner was turned off, and one where the air-conditioner was cooling down during the whole measurement.

Measure 2: The air-conditioner was turned off.

Filename: 6_17_2011__2-52-36PM__focus_data__rot_30__stsize_0.45__trigStart_0__velo_10__acc_5_noAC.dat

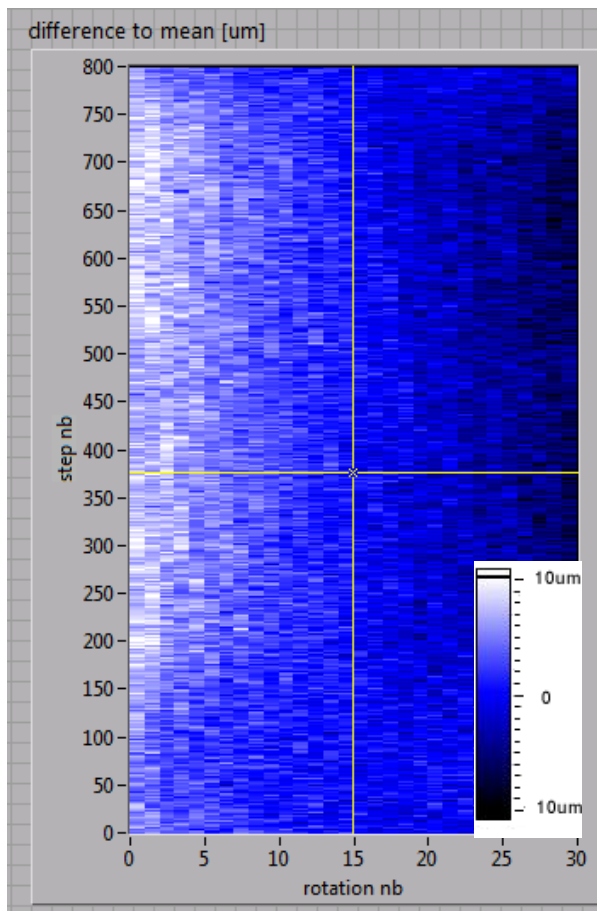


Fig. 58 - difference to mean without auto AC

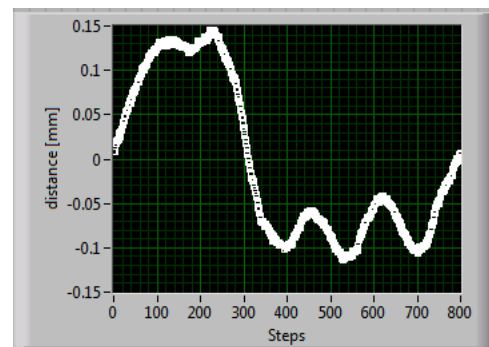


Fig. 59 - shape of the disc

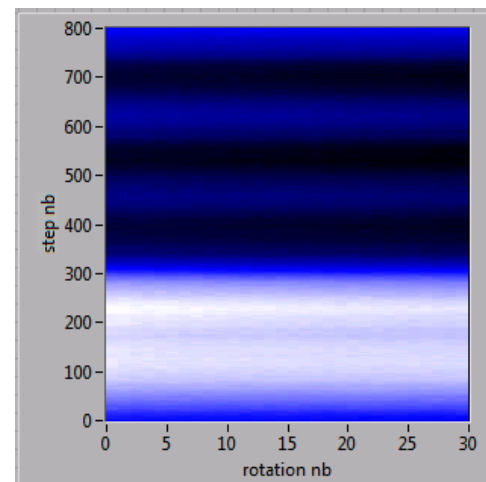


Fig. 60 - overall plot without AC

For this measurement the air-conditioner was turned off for entire scan.

This measurement took 18 minutes. During that time without air conditioner, the temperature in the room increased about 2° F (which corresponds to ~1° C). This temperature values were taken from the thermostat of the air-conditioner and are therefore not very precise.

Measure 3: The air-conditioner was turned on after the first rotation of the disc.

Filename: 6_17_2011__3-20-

58PM__focus_data__rot_30__stsiz_0.45__trigStart_0__velo_10__acc_5__acONafter1turn.dat

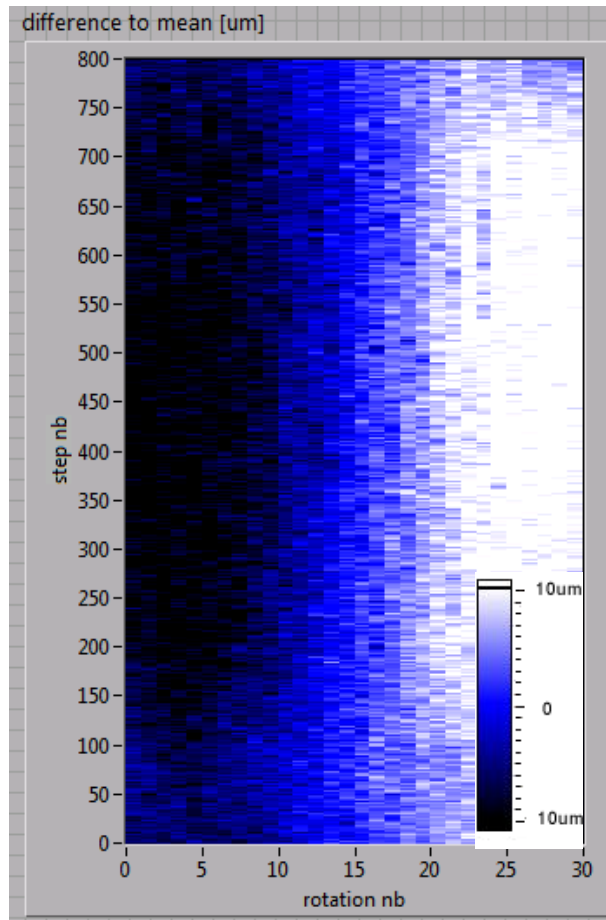


Fig. 61 - difference to mean with auto AC

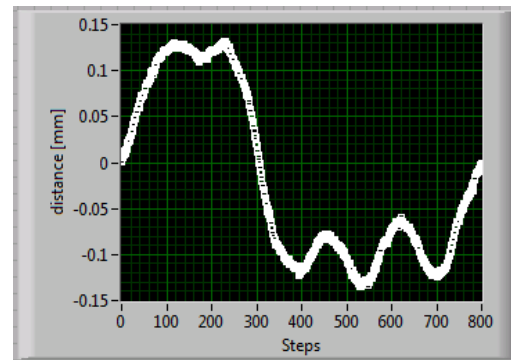


Fig. 62 - shape of the disc

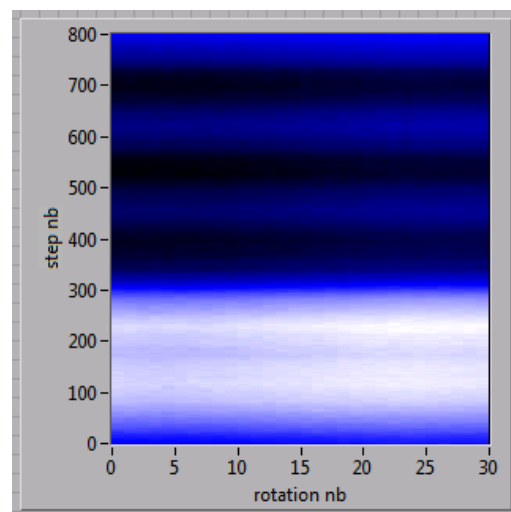


Fig. 63 - overall plot with AC

For this measurement the air-conditioner was running the entire scan. The thermostat was turned low enough to keep the air-conditioner running the entire time. The whole measurement took again about 18 minutes. By comparing Fig. 58 and Fig. 61 which show more or less opposite behavior, it seems to be evident that the measure of the laser distance sensor depends on the room temperature. This does not cause many problems if the system runs in autofocus mode, because the actual focusing data is never older than a couple of seconds. However if the system uses the gathering files to control the focus, the temperature might pose problems. To scan one rotation of the disk, the system takes 45seconds. A complete four pass scan of one rotation (with spinning back after every scan) takes about 6 minutes. If during the gathering of the data and the next 3 passes the air-conditioner turns on, the Passes will very probably have an offset caused by the instability of the temperature.

Measure 4: Air-conditioner in automatic mode, measure over longer time durance.

Filename: 7_11_2011__3-14-

26PM_focus_data_rot_60_stsiz_0.450_trigStart_0_velo_10_acc_5ac_on_76.dat

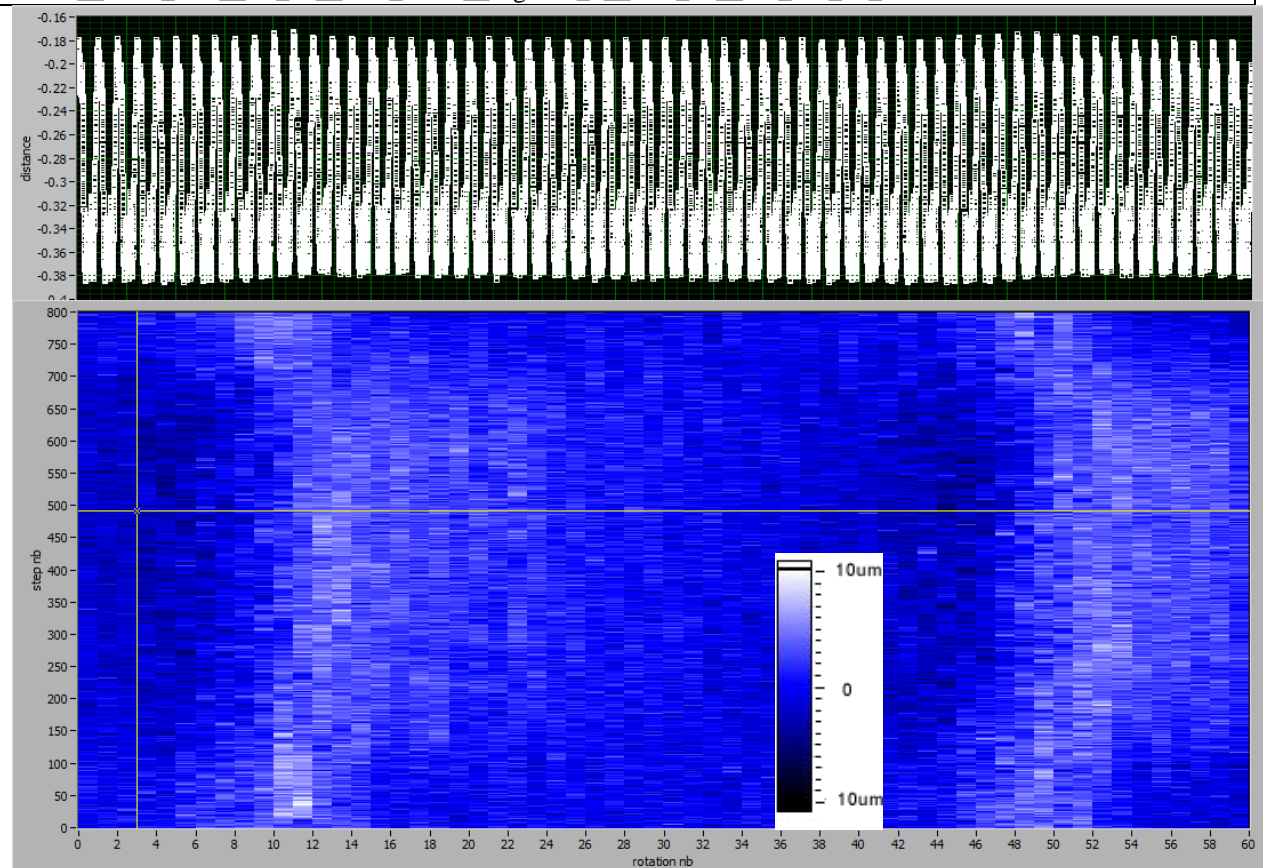


Fig. 64 - Measure over longer time durance

For this measure, the air-conditioner was again in automatic mode. The plot shows 60 revolutions of the disc. This corresponds to 36minutes. The upper plot shows the measured distance data and the lower plot shows this same data with subtraction of the mean value. It is very well visible how the whole system moves twice up and down. The time between those two movements corresponds to the time the air-conditioner turned on and off.

3.4.4 New scanning method: dithering

Because the result of the multiple pass scan with the new focusing tool was not as good as hoped at the beginning, another idea to acquire more datapoints was tested. Instead of doing multiple pass scans the data could be acquired using data dithering. Advantage of this method would be that the time between two scans next to each other would be much shorter than in multi pass scans (where it is around 90 seconds). So the idea is to set the rotating speed of the disc four times slower and move the translation disc up and down while the probe is acquiring data.

So if the red points are the usual scans in a spacing of about 0.02 degrees, the blue points would be the new additional points. By backcalculating each points origin, we would have the same data amount as with a multi pass scan, but the time between the diffrenet points would be only a few milliseconds.

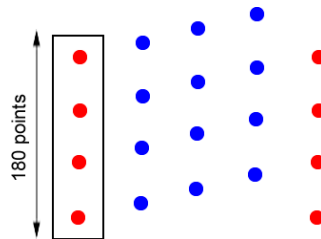


Fig. 65 - Data dithering

To realize a scan with this method, the translation stage has to perform synchronized with the rotation stage movement. The ideal form of this movement would be a saw tooth movement. There are different methods to control such a movement, but there are different problems to keep it synchronized. The XPS motion controller has an analog tracking function implemented, which is already used in the project to control the autofocus. Taking advantage of this feature, it was decided to use an external signal generator to produce a saw tooth signal which will be triggered by the rotation stage.

The position of the stage using analog tracking is set by the following equation:

$$\text{Position} = \text{InitialPosition} + (\text{AnalogValue} - \text{Offset}) * \text{Scale}$$

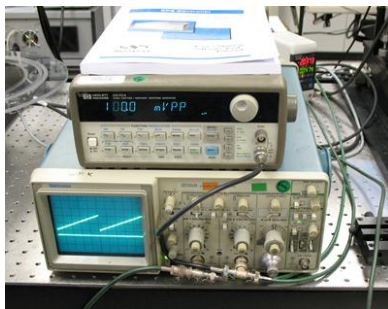


Fig. 66 – Saw tooth signal generation

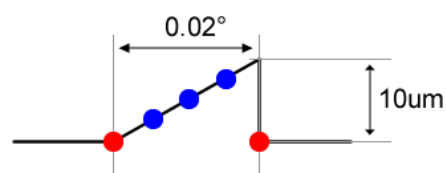




Fig. 67 - Saw tooth with points

Rotation speed	2°/sec
Step size of regular measurements	0.02°
Frequency of saw tooth signal	$\frac{2^\circ / \text{sec}}{0.02^\circ} = 100\text{Hz}$
Amplitude of the movement	10 microns

Performance measures

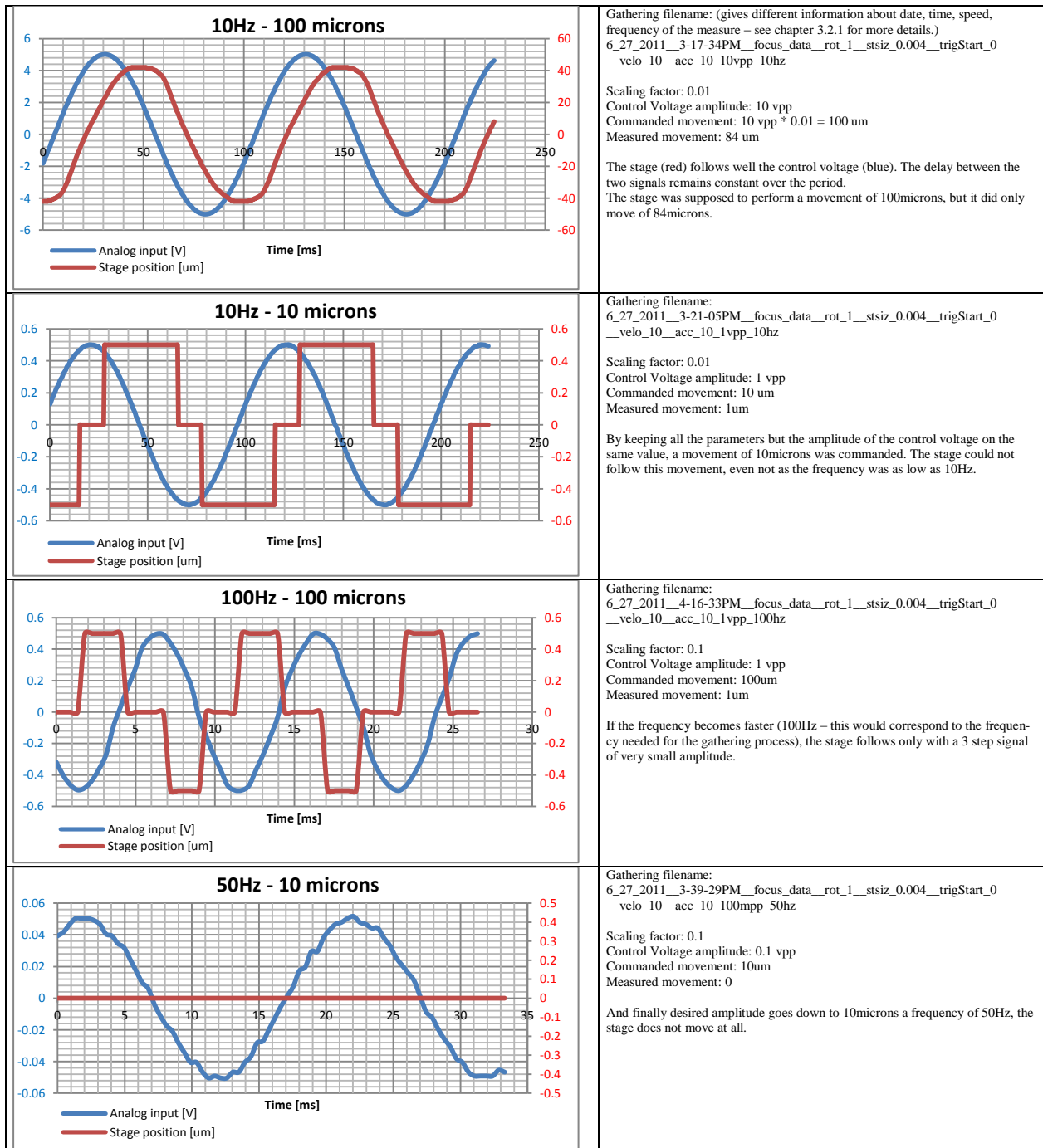
To check if such a movement with the translation stage would be possible, different measures were taken. Currently there are two different linear stages in use for this audio project at LBNL. The servo motor stage (the slower one) is at this moment used for the disc system, the linear motor stage for the cylinder system. If it would be necessary they could be exchanged, because at this time only slow movements are performed.

Servo motor stage: ILS250CC	Linear Motor Stage: XML210
 <p>Fig. 68 - ILS-250CC</p>	 <p>Fig. 69 - XML210</p>
Motor: DC servo motor Maximum Speed: 100 mm/s Resolution: 0.5 μ m	Motor: Brushless Linear DC motor Maximum Speed: 300 mm/s Resolution: 0.001 μ m

With both stages different measures were taken in order to check if the desired movement would be possible with one of those stages. The measures were taken with the same tool which logs the distance sensor data (chapter 3.2.1).

Measure of the DC-motor driven stage ILS-250CC

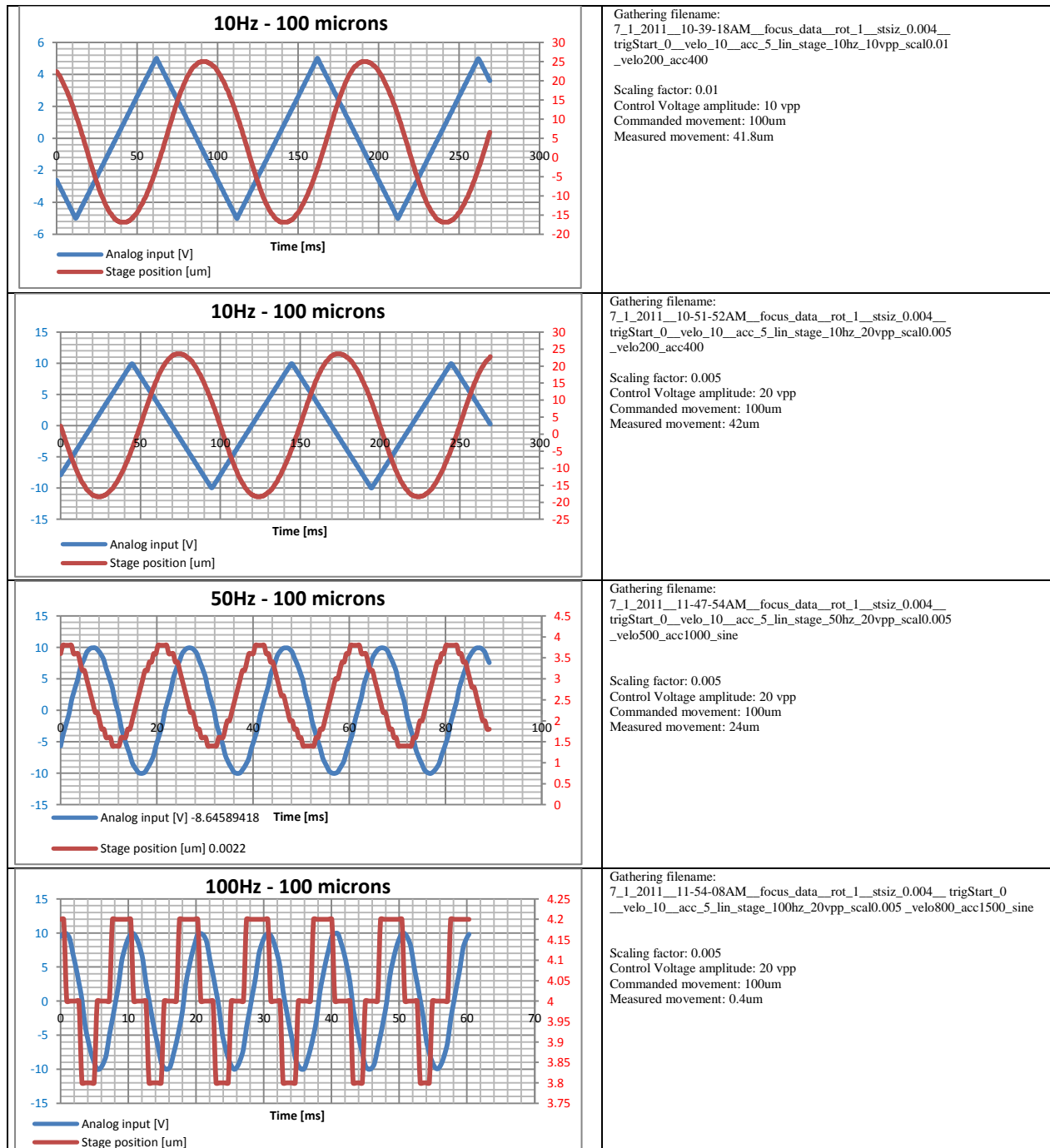
To prevent the stage from fast accelerations, the first measurements were taken with a sinus signal and on a frequency of 10Hz.



Using the servo motor driven stage to perform the desired movement shown in Fig. 67 with a frequency of 100Hz is not possible.

Measure of the linear motor driven stage XML210

Similar measurements that were taken for the dc motor driven stage were also taken for the linear motor driven stage. The stage position datasets are all not exactly around zero. This offset is only because the stage was not at zero at the beginning and does not affect the commanded movement. Instead of using a saw tooth signal, it would be also possible to use a triangular signal. This would avoid the fast acceleration of the saw tooth and still be easy to compute the points back to their origin.



At the necessary frequency, the stage is like the first measured stage, not able to perform the desired movement anymore.

If the dithering method will be further developed, a faster stage (probably a piezoelectric stage) will be necessary. During this project, no more analysis on data dithering will be done.

3.5 Conclusion

The idea of logging the focus-data in a file and use it in the following passes of the same region to control the focus works. However the result is not as perfect as hoped. The Different passes still have an offset. This offset seems to be less random than it is the case if the data is taken with the autofocus system. The problem with the gathering focus is that the time between the data which is used to control the focusing stage and the scan itself is long (about 6 minutes in a four pass scan). As described in chapter 3.4.3, during this time the temperature in the room will not be stable and this is the main reason for the offset which can be observed finally on the data. The gathering focus is a good option for very warped or cracked discs. In contrast to the before used autofocus, the gathering focus allows to set different filter parameters depending on what disc the user wants to scan.

Not being able to remove completely the offset during the different passes, a software tool (MatchPass V3) was created to perform this duty. The details about this tool are described in chapter 4.2.2.

The MPLS focus seems to be a good tool for discs without big discontinuities or discs which cannot in a good way be measured with the laser distance sensor (for example transparent plastic or aluminum discs).

3.5.1 Future work suggestions

To minimize the time during scanning the same region of the disc multiple times, the idea of data dithering was analyzed. Unfortunately the motion stages available at LBNL were not fast enough to perform such a movement. Using a piezoelectric stage, this could probably be corrected and could possibly be a good method to test in the future.

The mean Z function which computes the upper level of the sound carrier is used for the MPLS focus and for the findZ function. Mean Z works currently not for all the discs. The brilliance has to be on a good level and saturated points are causing problems. This function should be improved. Per example saturated points should not be taken into account and something like a “reflection coefficient” which determinates the maximal brilliance of the disc should be implemented.

Furthermore the PID regulator of the MPLS focus is not optimized yet. The parameters or maybe the whole regulator should be improved. Doing those two things would probably make the MPLS focus work in a more accurate way.

The gathering focus has the problem that it uses for the whole disc the same reference point (the point where the user is setting the desired height at 0° before starting the scan). If the disc becomes higher or lower towards its center, the probe is going out of range. This can very simply be corrected by saving this first reference value into the global and then compute the difference after every new gathering.

Another useful tool would be to combine the MPLS focus with the laser distance sensor. The measure of the laser distance sensor could be used in cases of cracks as “additional security” to prevent the probe from going out of range. Or once the MPLS lost the tracking, the laser could be used to readjust the height.

4 Software part – data processing

All the analysis and realizations about the software part of the project are documented in this chapter. The software part refers to the way the acquired data is processed, respective of how the centers of the grooves are detected and how the audio is reproduced. The program which performs the data processing is called PRISM and it is coded in C#.

PRISM is an interesting but very complex tool. It has been further developed over the last few years by different people. Most of the features in PRISM are described in the documentation “*New Probe for Depth Estimation of Records: software.*” by Adrien Nicolet (4).

4.1 General problem analysis

PRISM does a good job of processing single pass data. However as soon as multiple pass scan data is loaded, strange results are appearing. The centers of the groove hardly detected and the audio quality is poor. Those results are caused by the algorithms of PRISM which were originally developed for single pass scan data. The goal of this part of the project is to analyze those algorithms and to adapt them for multiple pass scan data.

Two key features of all the functions contained in PRISM were analyzed and improved. One is MatchPass which corrects defaults in the datasets and the other is FitLine, an algorithm which detects the center of the grooves.

4.1.1 MatchPass

Between two rotations (not multiple pass scans of the same surface, but different surface regions of the disc if the translation axis moves to 1.8mm), the data is usually not exactly on the same height.

Additionally it's possible that the record was not flat under the probe. The result of those factors is that the data looks like a saw tooth signal (see Fig. 70). The in PRISM2010 implemented function Match Pass V2 does a very good job of correcting the different heights of different passes. It also corrects the slope if the data is not horizontally aligned.

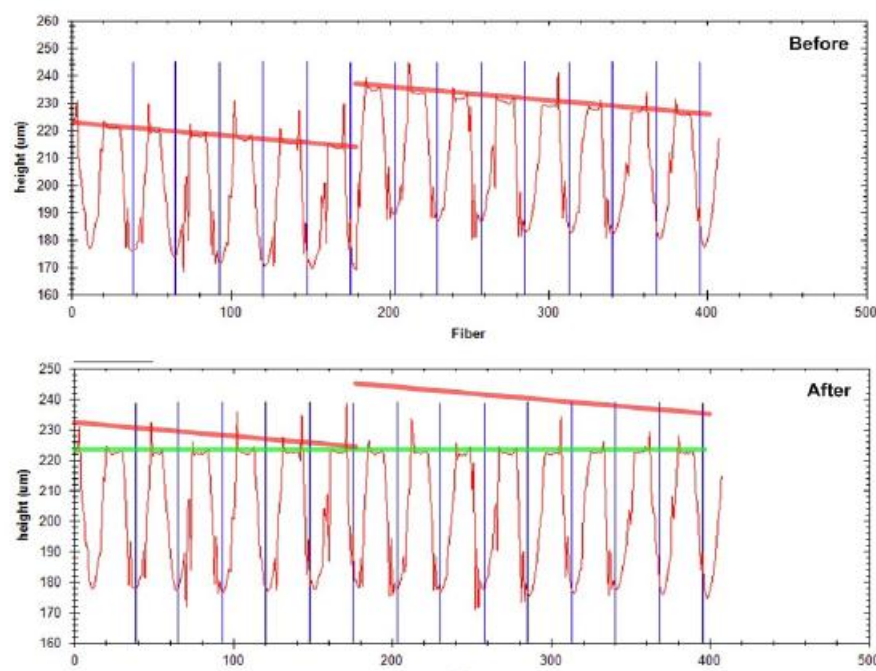


Fig. 70 – Match Pass V2 (4)

MatchPass V1 and V2 had nothing to do with processing the data multiple pass scans! It was only about putting the data of consecutive scans of different radiuses together.

The problem is, that this function was designed for single pass scans and does not process the multi pass scans in an ideal way. Match pass V2 takes 180 following points of the acquired data, finds the points on the top of the disc by considering the energy of the points, fits a linear equation through those points, and uses its slope to put all those 180 points to the same height level every time. This works very well in a single pass scan. However if a multi pass scan data file is being processed, it's not ideal to take 180 points together every time, because the correction will split and correct the data not at the point where a new pass begins.

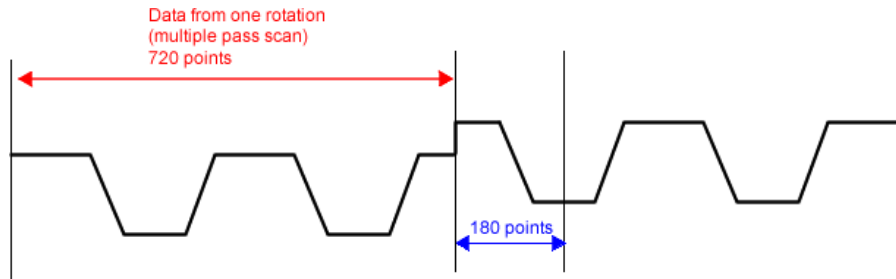


Fig. 71 - Data of multiple pass scan

4.1.2 FitLine

PRISM contains different methods to find the center of the grooves which is finally computed to the audio file. Available are FitLine, FitLine V2, Derivate, Quadratic and fit. The algorithms of all those methods are described in the Documentation "*New Probe for Depth Estimation of Records: software.*" by Adrien Nicolet (4).

The best working and therefore most used method is FitLine V2. Here a short explanation of how it works: Two parameters have to be entered: **Fit Num** and **Width**. **Fit Num** is the number of points taken in account to fit the linear equation through (green lines on the figure). **Width** is the length of the horizontal lines (black on the figure).

The algorithm starts at the point where the groove tracking positioned the first estimation of its center (blue lines on the figure). Then it starts analyzing the points on the left and right side of this line and checks one point after the other until it finds two points on the same height in a distance of **Width**. Once those two points are found, it uses the **Fit Num** points around those two points to compute the linear equation. Then a horizontal line with the length **Width** is inscribed in every groove so that this line touches both before computing linear equations. The new center of the groove is the middle of this line.

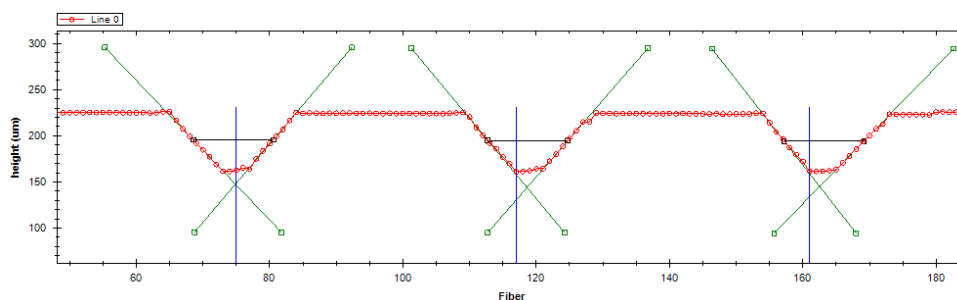


Fig. 72 – FitLineV2 processing single pass data

As visible on Fig. 72, the center of the groove after FitLineV2 (center of the horizontal black line) is much better detected as after the first estimation (vertical blue line).

Similar to the MatchPass function, this works well for single pass data, but as soon as multiple pass data is processed the algorithm shows strange, often inexplicable behaviors. Most likely this is because the algorithm was designed for single pass data.

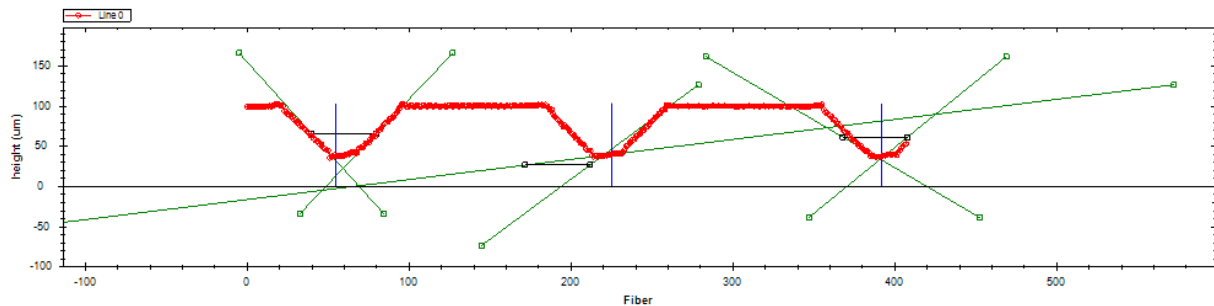


Fig. 73 - FitLine V2 processing four pass data

Fig. 73 shows very clearly the defaults of FitLine V2 in multiple pass scan. The first groove was detected very well.

The center of the second groove however was positioned completely wrong. Such behaviors of FitLine could occur on positions where the raw data is poor which means that the scan of the groove is not good. However the points determining this groove are good, there are no bad points to be found.

4.2 Realizations

4.2.1 Adaptations in the GUI

PRISM provides three plots giving information about the loaded data: one is a deepness picture of the opened file, one is only a small part of this same image (zoom function), and the last is a plot of data points on a specified place of the file (see chapter 2.5.7 for more details). By clicking on one of the first two images, PRISM shows the corresponding data in the plot. For debugging and parameter optimization purposes, it was until now hard to see exactly the same part of data twice, because the user had to click exactly twice on the same point in the images. To remove this default, textboxes were added at the bottom of the plot. As soon as the user clicks in the image, the current coordinates are shown in those text fields. By entering manually coordinates into these textboxes and pressing enter, the plot loads the corresponding data therefore entering the required coordinates. This allows the user to compare exactly the same position of the data with after adapting the parameters.

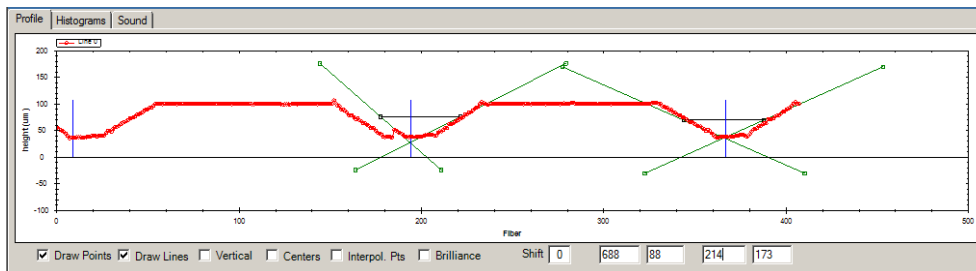


Fig. 74 - old PRISM GUI with FitLineV2

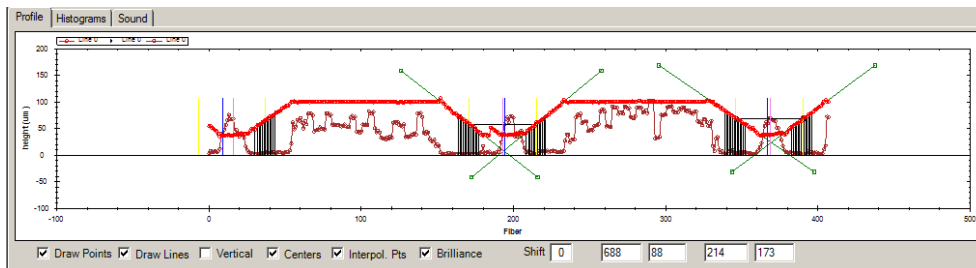


Fig. 75 - new PRISM GUI with FitLineVM

Items on both plots:

Red points: Scanned data points.

Blue line: First center estimation computed during groove tracking.

Green lines: Line fitting on the groove walls

Black line: Line which is putted horizontal between the two green lines – the center of the black line determinates the final center of the groove.

Additional items in FitLineVM:

Yellow lines: Starting point of the line fitting.

Black lines: Points taken into account for the line fitting.

Magenta line: Computed final center of the groove.

Brown points: Brilliance of each point.

4.2.2 MatchPass V3

While MatchPass V2 took 180 points together every time to apply the correction of the height and slope, MatchPass V3 checks first if the file to process contains multiple pass data. If so, every pass is processed as single data set.

Instead of taking every time 180 consecutive points like MatchPass V2 (which gives obviously bad results), MatchPass V3 takes 180 points of one pass, searches the points on the top of the disc and computes the slope. Using this slope, it repositions all the 180 points.

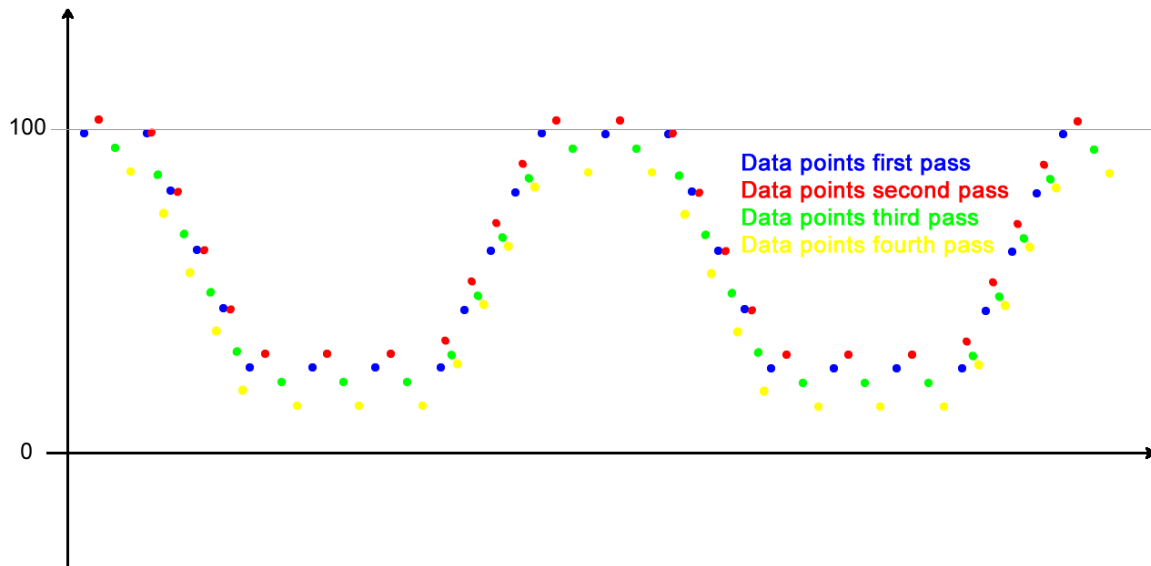


Fig. 76 - Four pass scan data structure

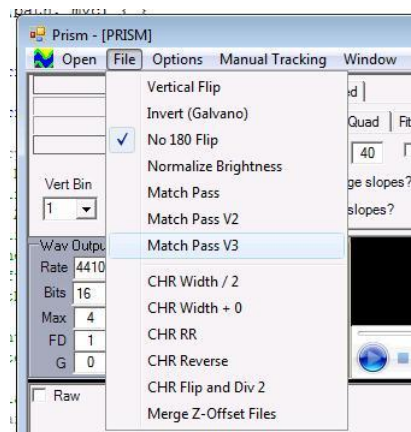


Fig. 77 - Feature MatchPass V3

Another change from V2 to V3 is the level where the height points are stabilized. For further processing of the points the absolute height of the points is not important. Match pass V2 took the height of the first 180 points of every line and adjusted all the following passes to match to this height. If this height of the first pass is detected wrong, the whole line will be adjusted to a wrong height. Match pass V3 simply uses a default value of 100 microns and sets all the data points to this height. This allows, by analyzing the data, one to see easily if the data is on the right height or not.

4.2.3 FitLine VM

Taking the algorithms of FitLineV2 a new version of the class under the name FitLineVM has been developed. The structure is very similar to FitLineV2. FitLineVM has some new parameters, the plot which shows the data processing has been improved and the selection of bad points is done in another way.

A main change from FitLineV2 to FitLineVM is the plot on the bottom of PRISM. Whereas FitLineV2 only showed the interpolated lines, FitLineVM shows now more details. Therefore it is now easier to understand why the center was computed on a certain point and if the result is bad, how this could be improved. To control these new features, three new checkboxes has been added on the bottom of the plot: “Centers”, “Interpol Pts” and “Brilliance”. Comparing Fig. 72 with Fig. 78 makes the new details visible. First the final center of the groove is now marked by a violet line. The two points where the line fitting is starting are marked with yellow lines and the black lines are marking the points which were taken into account for the line fitting. The last version of FitLineV2 just showed the blue line which is the first estimation of the groove computed during tracking, the two green lines corresponding to the line fitting and the black line which determinates finally the center. Fig. 72

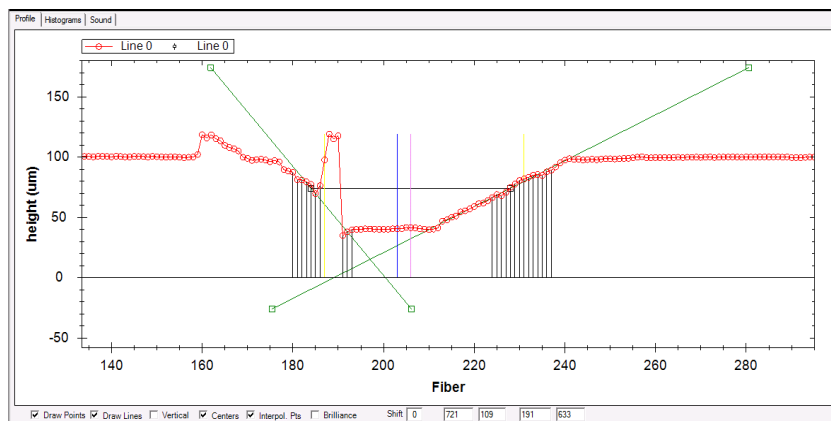


Fig. 78 - Data processing with FitLineVM

FitLineVM has additional to the parameters “Width” and “Fit Num” some new parameters like “Max Height”, “Limit Dist” and “Max Delta”. These parameters are used to select bad points.

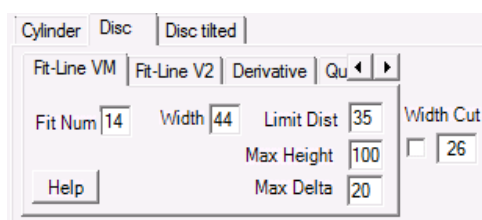


Fig. 79 - FitLineVM parameters

Fit Num is the number of points taken into account for the line fitting.

Width is the width of the horizontal line which, centered between the two line fittings determinates, finally the center of the groove.

Limit Dist is the distance from the tracking center (blue line) which the determination algorithm maximal goes.

Max Height determinates the maximal height of the points to be taken into account.

Max Delta determinates the maximal height difference between two points to be viewed as good data point.

4.3 Tests and comparisons

4.3.1 Performance of MatchPass V3

The following data is a four pass scan. The focus for the scan was controlled by the gathering focus. The five plots show every time the same raw data processed by the different versions of MatchPass. This part of the data represents the first and the last groove between two rotations. This means that the probe moved to 1.8mm between scanning the first and second groove.

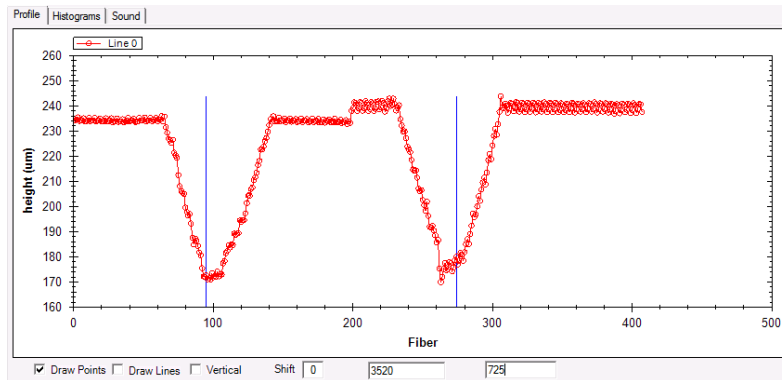


Fig. 80 - Data without MatchPass

The first plot shows the raw data. In the middle of the plot the height difference between the rotations is very well visible. Especially in the second half of the plot the offset between the different passes is visible as well.

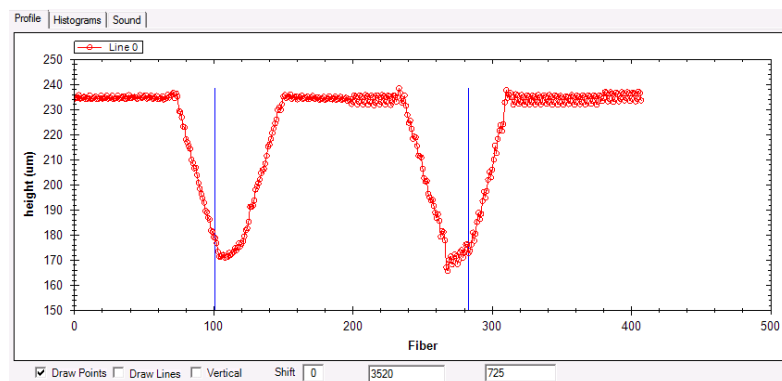


Fig. 81 - Data with MatchPass V1

MatchPass V1 is able to adjust the height of the different rotations.

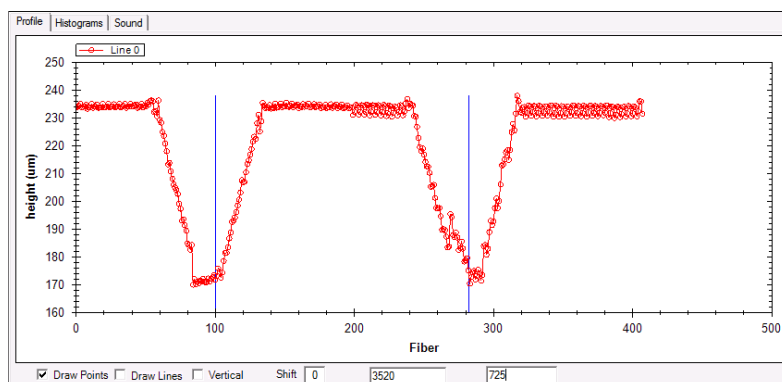


Fig. 82 - Data with MatchPass V2

MatchPass V2 would be able to adjust the slope of the data. Hence this part of the data was already flat and this functionality is not visible. However since MatchPass V2 does not treat multiple pass scans in a correct way, the data seem to be worse after the MatchPass V2 processing than previously encountered.

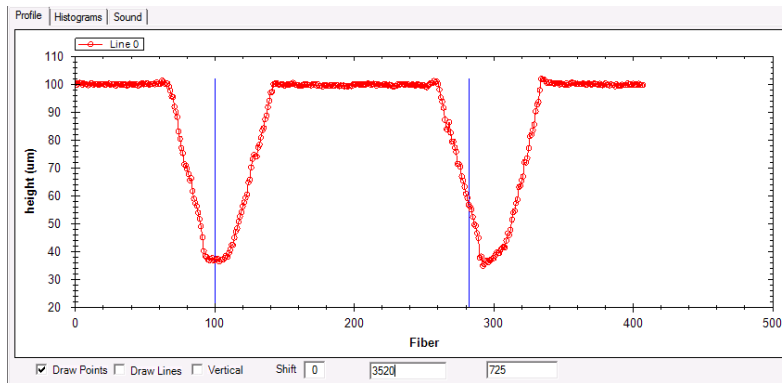


Fig. 83 - Data with MatchPass V3

With the good results of MatchPass V3, a big part of the offset problem which occurred while scanning the disc due to the focusing problem is solved as well. The second part of the data in Fig. 80 contains this typical multiple pass offset. Comparing Fig. 80 with Fig. 83 shows that this offset disappears after the correction realized with MatchPass V3.

Running MatchPass V3 the data points between the different rotations and between the different passes are now adjusted to the same level. Additionally, the upper level of the disc is now always at 100um.

4.3.2 Comparaison FitLine V2 – FitLine VM

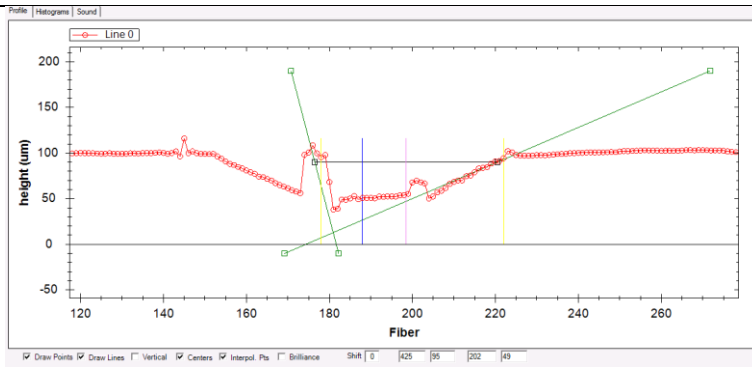


Fig. 84 - Data processing with FitLineV2 ex1

FitLine V2 did not detect that the peak of five points on the left side bad data points are. It used these points to for the line fitting. The result is a completely wrong groove wall estimation (left green line) which causes bad center estimation (magenta line).

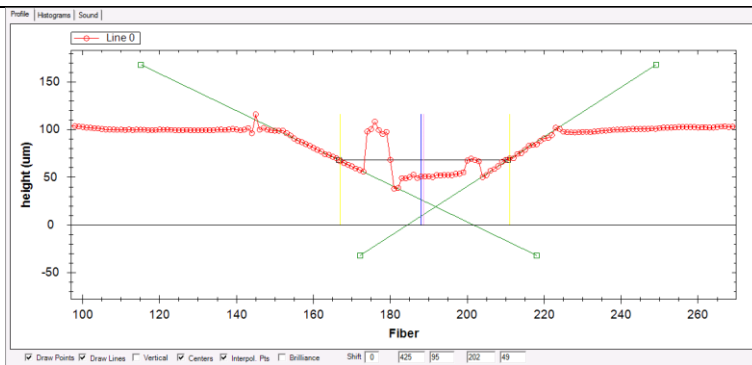


Fig. 85 - Data processing with FitLineVM ex1

FitLine VM detected these points as bad because of their absolute height their difference to the rest of the groove wall. Therefore the line fitting started further on the left side (yellow line).

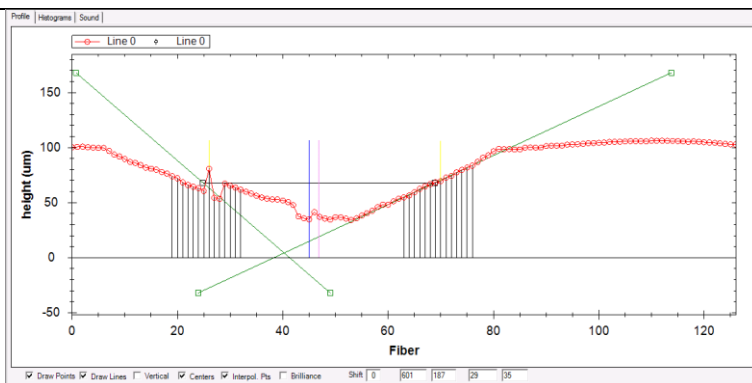


Fig. 86 - Data processing with FitLineV2 ex2

Fig. 86 and Fig. 87 were made with the GUI adaptations of PRISM. The yellow line shows the start point of the line fitting, the black lines show the points taken into account for the line fitting and the magenta line shows the computed final center of the groove.

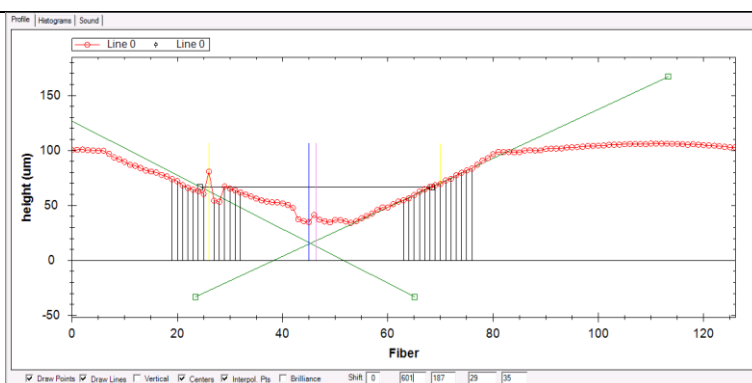


Fig. 87 - Data processing with FitLineVM ex2

On left groove wall of Fig. 87, one point was selected as bad point by FitLine VM. As result the line fitting is, even if it is still not perfect yet, much better without this point than before.

Following plots show the frequency spectrum of a 10 seconds record made from a disc in relatively good conditions. It is a four pass scan from a “Les Paul” record. The corresponding data files are on the DVD.

Fig. 88 shows the spectrum of the audio if FitLineV2 is applied. The violet plot shows the data if the averaging method (Fig. 31) is applied. Doing this produces good sound . If all the points of the four pass scan are separately processes, the audio is more or less just noise (green plot).

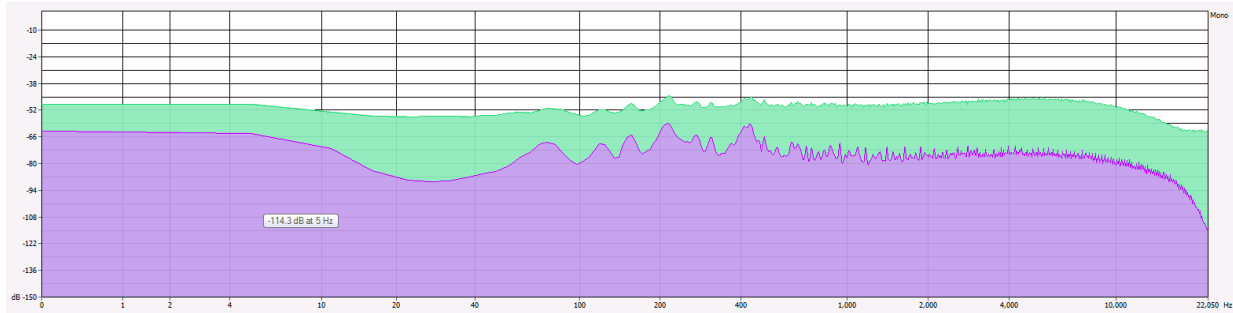


Fig. 88 - FitLine V2

Fig. 89 shows the same details for FitLineVM than the previous plot. The overall amplitude is in the averaged version (orange) smaller. This is because the computed absolute movement becomes smaller if the points are averaged which has no influence to the audio quality. Using FitLineVM, the sound quality is better without pass averaging.

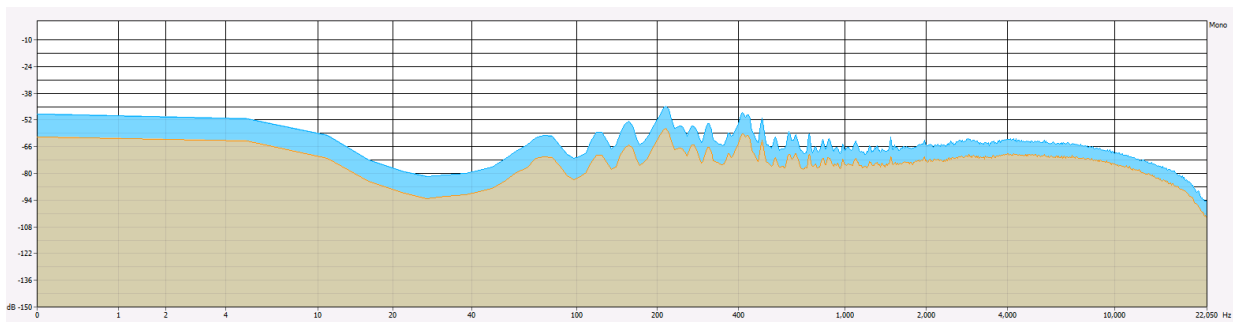


Fig. 89 – FitLineVM

Fig. 90 shows all four spectrums in one plot. Green is the non-averaged FitLineV2, blue is the non-averaged FitLineVM, orange is the averaged FitLineVM and violet is the averaged FitLineV2.

FitLineVM has in both cases a lot of noise in the higher frequencies. This is due to the error that at the current state of FitLineVM no interpolation is made for points where no center estimation could be made. This produces this white noise which is covering the high frequencies.

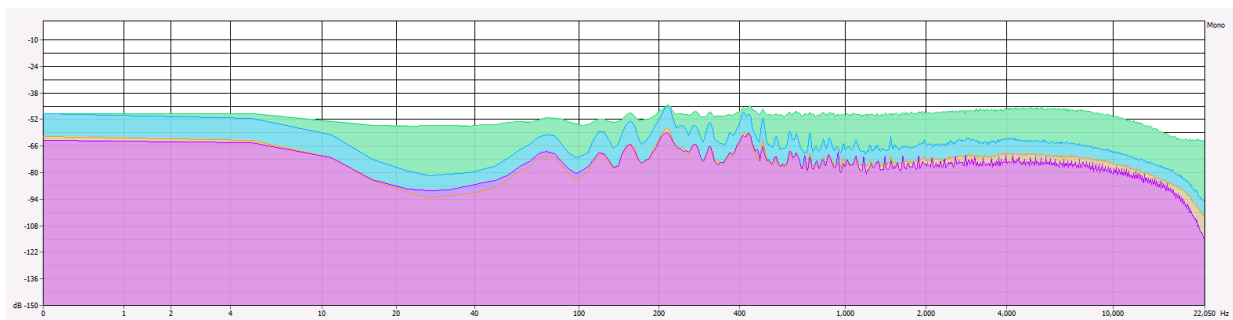


Fig. 90 - FitLineV2 - FitLineVM

4.4 Conclusion

Adding the coordinate selector to PRISM allows one to compare a specified region of the disc with different parameter settings. This is very helpful to debug the fitting algorithm if strange behaviors are encountered.

Adapting MatchPass for multiple pass scans solved two problems in one. First, the data of the different rotations is now correctly aligned as was previously the case with single pass data. Additionally, MatchPass is now used to correct the offset between different passes in a multiple pass scan. Therefore the default in the raw data, caused by different variables encountered in the scanning process, can now be corrected without losing information about the grooves.

4.4.1 Quantitative comparison of the different focusing systems

Until now it was not possible to have any quantitative comparison between the different focusing systems. This was due to the different offsets which were not constant over the whole data. Looking at just one point of the data does not give any indication if the data that was taken by autofocus or if the data taken by gathering focus is better. Both look more or less the same, even when the data taken by autofocus appeared more like a random distribution and the data taken by gathering focus appeared more like a linear increment or decrement between the passes.

Since MachPass V3 finds the points on the top of the disc, computes its slope and adjusts its height to a given value, it's possible to use the height difference as a quantitative value of how far the points were away from the mean value. Furthermore, doing this corresponds to measuring the standard deviation of the points for both methods.

The same region of the disc “In the evening by the moonlight” was scanned three times with the three different focusing systems. All the scans are four pass scans. This data is available on the associated DVD.



Fig. 91 - Disc in the evening by the moonlight

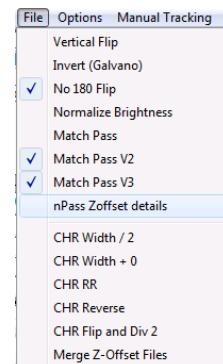


Fig. 92 - nPass details

Executing the function nPass Zoffset details (Fig. 92) computes the mean height of all the taken scans and its standard deviation. This function is only available if MatchPassV3 was used to correct the data.

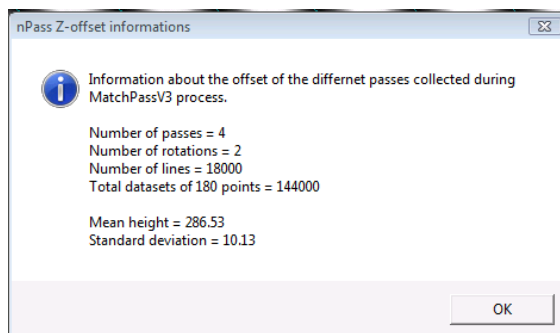


Fig. 93 - nPass details result

Auto focus	Mean height = 286.53 Standard deviation = 10.13
Gathering focus	Mean height = 250.49 Standard deviation = 12.95
MPLS focus	Mean height = 272.46 Standard deviation = 5.48

This value will be changing for the different kinds of discs. For this disc, MPLS focus will probably deliver the best data because the passes matched very good together and only a small height correction of has been made.

4.4.2 Future work suggestions

MatchPass V3 works well. But by using the same algorithm for the MPLS focus, it could be observed that single bad points are disturbing the measure of the upper level. Therefore these outliers should be better filtered before the height is computed.

FitLine VM needs more improvement. The multiple pass scan data is processed in a better way and lots of the bad points are filtered. But there is still a lot of work to do. A current problem of FitLine VM is that all the points where the line fitting failed no position estimation is given. This could be corrected with the interpolation of this point using the prior and next valid data point.

Another idea for improving FitLine would be to instead of processing each “groove cut“ by itself to create a 3D model of defined number of such „groove cuts“ and fitting a plane through the groove walls. This would permit a better processing of data with bad points.

5 Acknowledgments

In the end of the project I'd like to thank all the people that made it possible to work on this project at the Lawrence Berkeley National Laboratory. Working on such a project in that laboratory has been a unique chance which I very appreciated. Special thanks go to the supervisors at LBNL Carl Haber and Earl Cornell, the EIF professors Wolfgang Luithardt and Ottar Johnson and the project expert Luciano Sbaiz.

The University Of Applied Sciences Of Western Switzerland also has to be thanked for allowing the students to go abroad for such projects and financing it.

6 References

1. **Severin Nowak and Sven Hezel.** *Extraction of Sound using 3D*. 2008.
2. **Raynald Seydoux and Philippe Ballestraz.** *Estimation of groove position*. 2009.
3. **Mueller, Tobias.** *New Probe for Depth Estimation of Records: hardware*. 2010.
4. **Nicolet, Adrien.** *New Probe for Depth Estimation of Records: software*. 2010.
5. Wikipedia - Phonograph. <http://en.wikipedia.org/wiki/Phonograph>. [Online]
6. Wikipedia - Schallplatte. <http://de.wikipedia.org/wiki/Schallplatte>. [Online]
7. Revolutions in sound recording.
http://open.jorum.ac.uk/xmlui/bitstream/handle/123456789/1038/Items/TA212_3_section5.html. [Online]
8. Dipity. <http://www.dipity.com/chickenlover2004/Analog-vs-Digital-Recording/>. [Online]
9. Badenhausen. <http://www.badenhausen.com/VSR1Pickups.htm>. [Online]
10. Speakerbits. <http://www.speakerbits.com/speaker-repairs/about-catridges-of-operation/article-23.aspx>. [Online]
11. Wikipedia - Strain-Gauge. http://en.wikipedia.org/wiki/Strain_gauge. [Online]
12. **Stotzer, Sylvain.** *Phonographic record sound extraction by image processing*. 2006.
13. **STIL.** http://www.stilsa.com/catalog2/pdf/STILSA_MPLS.pdf. [Online]

7 List of figures

Fig. 1 - Player history	3
Fig. 2 - Phonautograph (5)	6
Fig. 3 - Edison and phonograph (5)	6
Fig. 4 – Different types of disc records (6)	7
Fig. 5 - Phonograph cylinder (6).....	7
Fig. 6 - Stylus motion (7).....	7
Fig. 7 - Different grooves (7).....	7
Fig. 8 - Groove dimensions of 78`s (4).....	8
Fig. 9 - Gramophone groove.....	8
Fig. 10 - Acoustical gramophone (8)	8
Fig. 11 - mechanical sound reproduction	8
Fig. 12 – Piezoelectric reading head (9)	9
Fig. 13 - Magnetic cartridge (10).....	9
Fig. 14 - Strain-Gauge (11).....	10
Fig. 15 - 2D disc scanning IRENE.....	10
Fig. 16 - Irene software.....	10
Fig. 17 - 3D scanning data	11
Fig. 18 - 3D software PRISM	11
Fig. 19 - Optical scanning system at LBNL.....	11
Fig. 20 – 3D Scanning system	12
Fig. 21 - Keyence distance sensor with controller	12
Fig. 22 - XPS motion controller.....	12
Fig. 23 - MPLS180	13
Fig. 24 - MPLS 180 data points	13
Fig. 25 - MPLS: chromatic confocal sensor.....	13
Fig. 26 - Sound reproduction	14
Fig. 27 - Disc scanning tool	15
Fig. 28 - Data distribution in multi pass scan.....	15
Fig. 29 - Disc data processing tool PRISM.....	16
Fig. 30 – Measure of Z-offset between different passes in a two pass scan.....	17
Fig. 31 - Multiple passes averaging	17
Fig. 32 - Warped disc.....	18
Fig. 33 - Autofocus	18
Fig. 34 - LTA-HS.....	19
Fig. 35 - Focus data saving	19
Fig. 36 - XPS cabling.....	20
Fig. 37 - 3D-Tools_GatherZ.vi	21
Fig. 38 - 3D-Tools_compare.vi.....	23
Fig. 39 - 3D-Tools_focus_v8.vi.....	24
Fig. 40 - Angle between MPLS and laser	25
Fig. 41 - Scaling factor measure	25
Fig. 42 - Scaling factor	25
Fig. 43 - MPLS focus.....	26
Fig. 44 - 3D-Tools_adjustFocus.vi - Block diagram.....	26
Fig. 45 - 3D-Tools_viewer.vi.....	27
Fig. 46 - 3D-Tools_global.vi	28
Fig. 47 - 3D-Tools_scan.vi	29
Fig. 48 - LK-Navigator	31
Fig. 49 - Eye program	31
Fig. 50 - Gathering controlled focus	33
Fig. 51 - Gathering controlled focus, good example.....	33
Fig. 52 - Gathering controlled focus, bad example	34
Fig. 53 - MPLS focus data	35
Fig. 54 - Data points MPLS focus.....	35
Fig. 55 – difference to mean with auto AC.....	36
Fig. 56 - shape of the disc	36
Fig. 57 - Overall plot with auto AC	36
Fig. 58 - difference to mean without auto AC	37
Fig. 59 - shape of the disc	37
Fig. 60 - overall plot without AC.....	37

Fig. 61 - difference to mean with auto AC	38
Fig. 62 - shape of the disc	38
Fig. 63 - overall plot with AC	38
Fig. 64 - Measure over longer time durance	39
Fig. 65 - Data dithering	40
Fig. 66 – Saw tooth signal generation	40
Fig. 67 - Saw tooth with points	40
Fig. 68 - ILS-250CC	41
Fig. 69 - XML210	41
Fig. 70 – Match Pass V2 (4).....	45
Fig. 71 - Data of multiple pass scan	46
Fig. 72 – FitLineV2 processing single pass data.....	46
Fig. 73 - FitLine V2 processing four pass data	47
Fig. 74 - old PRISM GUI with FitLineV2	48
Fig. 75 - new PRISM GUI with FitLineVM	48
Fig. 76 - Four pass scan data structure	49
Fig. 77 - Feature MachPass V3	49
Fig. 78 - Data processing with FitLineVM	50
Fig. 79 - FitLineVM parameters	50
Fig. 80 - Data without MatchPass	51
Fig. 81 - Data with MatchPass V1	51
Fig. 82 - Data with MatchPass V2	51
Fig. 83 - Data with MatchPass V3	52
Fig. 84 - Data processing with FitLineV2 ex1	53
Fig. 85 - Data processing with FitLineVM ex1	53
Fig. 86 - Data processing with FitLineV2 ex2	53
Fig. 87 - Data processing with FitLineVM ex2.....	53
Fig. 88 - FitLine V2	54
Fig. 89 – FitLineVM	54
Fig. 90 - FitLineV2 - FitLineVM.....	54
Fig. 91 - Disc in the evening by the moonlight.....	55
Fig. 92 - nPass details	55
Fig. 93 - nPass details result.....	55

8 Appendices

- Specification
- Weekly reports
- Planning
- On the DVD
 - Lab View Code
 - PRISM 2011
 - Scanned 4 pass disc data