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INSTITUTE OF AUTOMATION AND COMPUTER SCIENCE

ÚSTAV AUTOMATIZACE A INFORMATIKY

SAMPLE DIVIDER OPTIMIZED FOR A SPECIFIED GROUP OF BULK GOODS

VZORKOVAČ OPTIMALIZOVANÝ PRO ODBĚR ZADANÉ SKUPINY SYPKÝCH MATERIÁLŮ

MASTER'S THESIS

DIPLOMOVÁ PRÁCE

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Assignment Master's Thesis

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As provided for by the Act No. 111/98 Coll. on higher education institutions and the BUT Study and Examination Regulations, the director of the Institute hereby assigns the following topic of Master's Thesis:

Sample divider optimized for a specified group of bulk goods

Brief Description:

The first step in evaluating the quality of a material is taking representative samples of the material to be tested. For this purpose, a number of tools and techniques have been developed that allow more or less automated collection of representative samples. However, these tools are not universal. This is particularly evident in bulk materials, where the size, shape and density of the solid particles greatly influence the behaviour of the bulk material as a whole. It is often necessary to develop a technique or instrument that allows the collection of sufficiently representative samples of a specific material.

Master's Thesis goals:

The student will complete a survey mapping the techniques and instrumentation used to sample bulk materials. The student will design, build, and test a sampler to collect representative samples of a specified group of bulk materials.

Recommended bibliography:

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Ing. Pavel Heriban, Ph.D.	doc. Ing. Jiří Hlinka, Ph.D.
Director of the Institute	FME dean

ABSTRACT

This thesis concerns the development of an adjustable sample divider for seeds of different sizes and shapes. Its purpose is to produce representative samples of fractions set by the operator from the input material to be sampled. The main objective was to develop and test this type of sample divider. The sample divider was developed based on a mini conveyor belt with a sampling flap positioned at the end of the conveyor belt where the material is sampled into the sample and remaining material boxes. Four different types of conveyor feeders were developed and tested for the sample divider. The results of the test indicated that version C of the conveyor feeder gave the best results. In conclusion, the adjustable sample divider facilitates the production of representative samples of different seeds on a single piece of equipment, as opposed to the use of multiple commercially available sample dividers designed for specific sizes and shapes of material particles.

ABSTRAKT

Tato práce se zabývá vývojem nastavitelného děliče vzorků pro semena různých velikostí a tvarů. Jeho účelem je vytvářet reprezentativní vzorky frakcí, nastavených obsluhou, ze vstupního materiálu, který má být vzorkován. Hlavním cílem bylo vyvinout a otestovat tento typ děliče vzorků. Dělič vzorků byl vyvinut na bázi minipásového dopravníku s klapkou umístěnou na konci dopravníku, odkud se materiál dělí do boxů na vzorky a na zbývající materiál. Pro dělič vzorků byly vyvinuty a testovány čtyři různé typy dopravníkových podavačů. Výsledky testu ukázaly, že verze C dopravníkového podavače poskytuje nejlepší výsledky. Závěrem lze říci, že nastavitelný dělič vzorků usnadňuje produkci reprezentativních vzorků různých semen na jediném zařízení, na rozdíl od použití více komerčně dostupných děličů vzorků, které jsou určeny pro specifické velikosti a tvary částic materiálu.

KEYWORDS

sample divider, theory of sampling, representative sample, communication protocol

KLÍČOVÁ SLOVA

vzorkovač, teorie vzorkování, reprezentativní vzorek, komunikační protokol

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AUTHOR'S DECLARATION

I declare that this thesis is my original work, I have prepared it independently under the supervision of the thesis supervisor and using professional literature and other sources of information, all of which are cited in the thesis and listed in the reference list.

As the author of this thesis, I further declare that in connection with the creation of this thesis I have not infringed the copyright of third parties, in particular I have not infringed in an unauthorised manner on the personal copyright of others, and I am fully aware of the consequences of violating the provisions of § 11 et seq. of the Copyright Act No. 121/2000 Coll., including possible criminal consequences.

In Brno, 24. 5. 2024 . . . .

Jakub Rolný

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CONTENTS

1 INTRODUCTION

In order to perform a chemical analysis of seeds, it is necessary to obtain a representative sample. This is achieved by dividing the laboratory or field sample into small but representative subsamples, called increments, using a technique called sample division. This is done by sample dividers that are commercially available and that work most efficiently with spherical particles of the maximum diameter for which the divider is designed. For materials such as caraway, fennel or aniseed, which have an elongated shape with a stalk, commercial sample dividers are much less efficient. They also have very limited particle size adjustment (if any), which makes them very impractical to perform sample division on different types of seeds.

(a) Caraway [1] (b) Fennel [2] (c) Aniseed [3]

Fig. 1: Different Types of Seeds

The objective of this thesis is to develop an inexpensive automatic sample divider that is adjustable to different particle sizes, works with elongated shapes or seeds with stalks, and provides small representative increments of material that make up the final representative sample, which forms a certain fraction of the input material to be sampled. It is important that the sampling procedure does not compromise the accuracy and correctness of the sampling procedure, while simultaneously minimising the systematic and random errors. The primary objective of this sample divider is to facilitate the sampling of seed-type material, including nuts and grains, which may vary in size and shape from poppy seeds to white beans. The divider should be capable of sampling seeds with a total volume of up to 2 litres and a total weight varying from 5g to 10kg. The construction of the divider should be such that the components are easily cleaned, as contamination of the seed sample must be avoided. Moreover, the construction should not damage the seeds during division, as volatile compounds may be lost and the seeds subsequently sown. The design of the construction parts should be suitable for publication in Journals of open hardware, as the design should be accessible to everybody. Furthermore, the divider should be able to communicate with a laboratory environment.

A vibration drive was considered based on previous work by researchers at JKI (Julius Kühn Institute) on this divider. However, this could cause unmixing/-sorting of particles, which is better avoided. Therefore, a sample divider based on a mini conveyor belt was proposed by JKI. This sample divider may also be used for field sample division in the future. An external power supply of 12 V from a car battery was suggested as sufficient. Some of the components required for the development of the sample divider were supplied by JKI.

2 CURRENT STATE OF KNOWLEDGE

The theoretical section of this thesis provides an overview of sampling techniques and commercially available sample dividers, with a particular focus on the automatic sampling of flowing, unpackaged products. Secondly, an overview of industrial communication protocols is provided, which provides the necessary communication with the laboratory environment. The third section deals with conveyor belts, their construction and tensioning methods. The fourth section provides a brief overview of the theory of electric circuits. Finally, the fifth and sixth sections of the theoretical part focus on journals of open hardware and the specifications of the components supplied by JKI.

2.1 Intoduction to sampling

Sampling is the taking of samples from a material in order to obtain information on the composition of the total quantity with respect to one or more characteristics such as metal content, ash content, moisture, particle size, particle shape, etc. The sample is a portion of the total material under consideration and is used in the study of properties whenever a complete, i.e. 100 %, study of the total material is not possible, whether for economic reasons, when the method required to study large total quantities cannot be justified, or when the product is destroyed during analysis and can no longer be used [4].

Sampling is carried out according to a sampling plan which defines the type of sampling. Sampling may be systematic or random. In the case of a random sample, the individual samples, also known as elements, are taken independently and at random from the total material to be tested. The probability of being selected in the total sample must be the same for all samples of the same size. In contrast to the random sample, the systematic sample consists of individual samples taken at regular intervals of time, quantity or space, distributed over the total quantity of material. The first individual sample is still chosen at random. When choosing the interval between two individual samples, care must be taken to ensure that the sequence of the individual samples does not coincide with the natural variation of the attributes, as this can lead to unpredictable sampling errors. Despite these potential sources of error, the regular distribution of individual samples, i.e. systematic sampling, is preferred because it is easier to administer. The sampling plan also provides information on the number of individual samples included in the sample, which depends on the required precision, i.e. the variation that can be expected in the test results within defined confidence limits. The difference between the results of an investigation and the true content of the total is called sampling error. These errors are systematic when they lead to discrepancies despite theoretically infinite repetition of the study. These systematic errors are process-dependent. On the other hand, the measured value can be expected to be the true value on average, although random errors introduce uncertainties. Determining these errors is a task for mathematical statistics. The main parameters to be studied are the variances and their roots, the standard deviations [4].

Apart from the sampling method, sample size is the most important variable. It largely determines the magnitude of the variations to be expected. Conversely, a claim of precision with a given statistical certainty (confidence interval) corresponds to a minimum number of individual samples. Theoretically, a single sample is sufficient to determine the active ingredient content of an ideally homogeneous material. However, in practice, because of the analytical error that is always present, a certain number of values of the attribute must be determined. A further measurement uncertainty, the sampling error, arises if the material itself is inhomogeneous. The larger the sample and the more homogeneous the material, the closer, on average, the value of the attribute found using the sample will be to the true value [4].

If the material to be studied is made up of different parts, then these parts can be considered to be strata of the whole unit. The size and number of these layers is determined by the appropriate temporal, quantitative or spatial subdivision, i.e. the one that will lead to greater accuracy. From each stratum, one or more random or systematic individual samples shall be taken. The size and degree of homogeneity of each strata determines the number of these elements. This is called stratified random sampling. In some cases, this can lead to a significant improvement in sampling precision [4].

If the bulk material is divided into stages, e.g. railway wagons, pallets, sacks or bags, and only a proportion of the items are selected for testing at each stage, the procedure is called stage sampling. Individual stages can also be created by repeatedly dividing the sample at each selection of individual portions, as is often the case in practice. The optimum subdivision of the elements to be selected depends on the degree of homogeneity in each batch [4].

The selection of individual samples can be predetermined by the method of packaging and transport. In most cases, however, bulk sampling must be carried out by hand or using a sampling tool. In order to maximise the comparability of experimental results, technical details are often laid down in standards and guidelines. Of course, the tools that can be used depend largely on the condition of the material to be examined [4].

In the case of granular bulk materials that have already been crushed, samples are usually taken from the conveyor belt during transport or unloading [4].

If samples contain individual particles similar in size to the sample itself, then in addition to the number of individual elements in the sample and the type of sampling, the particle size and particle size distribution will also be considered as variables [4].

2.2 Sampling of cereal and cereal products

Sampling is a process that requires both an appropriate method and equipment. Any analysis of the characteristics of a lot and any interpretation of the results will be meaningless if the sample is not representative of the lot from which it was taken [5].

2.2.1 Terms and definitions

The following terms and definitions are employed in this section:

lot - specified amount of material from which a sample may be taken for the purpose of determining one or more characteristics [5]

sampling - the process of obtaining or producing a sample [5]

increment - the quantity of material collected from each individual sampling point of the entire lot at a single point in time [5]

aggregate sample, composite sample - sample resulting from the combination of two or more increments that were taken from the entire lot, combined and homogenized [5]

laboratory sample - sample prepared by homogenization and division of the aggregate sample prepared for shipment to the laboratory and intended for inspection or testing [5]

homogenization - thorough mixing by mechanical or manual means so that contaminants and physical properties are evenly dispersed throughout the aggregate or laboratory sample [5]

packed unit - quantity of grain or ground product packed in a bag or sack or sales package [5]

sampling error - that part of the total error estimate of a trait due to the heterogeneity of the trait, the nature of the sampling and known and acceptable flaws in the sampling plan [5]

2.2.2 General requirements

The subsequent stages of sampling are as follows:

1. Creating an aggregate sample by taking a specific number of increments.
2. Homogenization of the aggregate sample.

3. Reduction of aggregate sample to laboratory sample.

As the composition of many cereals is often not homogeneous and certain contaminants are unevenly distributed, it is necessary to take a sufficient number of increments and carefully mix them to create an agregate sample. This agregate sample can then be used to obtain one or more laboratory samples [5].

It is important to ensure that all equipment used is clean, dry, and free from any extraneous odours. Sampling procedures must be carried out carefully to protect the material from accidental contamination caused by rain, dust, or other sources [5].

Sampling procedures must be conducted within a short period to prevent changes in sample volatiles. If any of the sampling stages takes longer, the increments must be hermetically sealed, either individually or as a whole [5].

Measures should be taken to ensure the integrity of the samples from collection to use in the laboratory [5].

2.2.3 Sampling of unpackaged products

Sampling of unpackaged products refers to the collection of samples from both flowing and static cereals, using either mechanical or manual methods. The sampling of packed units is limited to static sampling, which is performed using manual procedures [5].

Sampling should ideally be conducted while the products are in motion, such as during loading or unloading, to ensure equal representation of all parts of the lot. If mechanical sampling methods are not available, manual sampling should be employed [5].

Sampling methods for moving lots, whether mechanical or manual, must be adjusted to the speed of sample flow [5].

To ensure the aggregate sample is representative, it is essential to use as many increments as possible [5].

Sampling of flowing unpackaged products

As the properties and composition of the lot may vary, increments should be taken from the entire lot. This means that the material should flow continuously [5].

The equipment should be arranged in a way that allows for a wide range of variation in the size of increments and sampling frequency for mechanical sampling [5].

Increments of a predetermined size should be taken at regular intervals based on the sample flow. This ensures that each part of the lot has an equal chance of entering the sampling device [5].

Number and size of laboratory samples

All the increments collected add up to a aggregate sample, which must be homogenized and divided, in order to prepare the laboratory sample [5].

The laboratory sample weight should be determined based on the type and requirements of the tests to be performed [5].

To determine contaminants, the laboratory sample weight must be between 1 kg and 10 kg. To determine additional properties, the laboratory sample must weigh at least 1 kg [5].

2.2.4 Laboratory sample

To obtain a laboratory sample, it is necessary to homogenize the aggregate sample properly before any separation procedure [5].

The aggregate sample is divided to obtain the required number of laboratory samples of the determined weight. It is important to use methods and equipment that can provide representative laboratory samples [5].

The required number of laboratory samples is determined based on the number of lots. One laboratory sample is needed for each lot and any remaining lots [6].

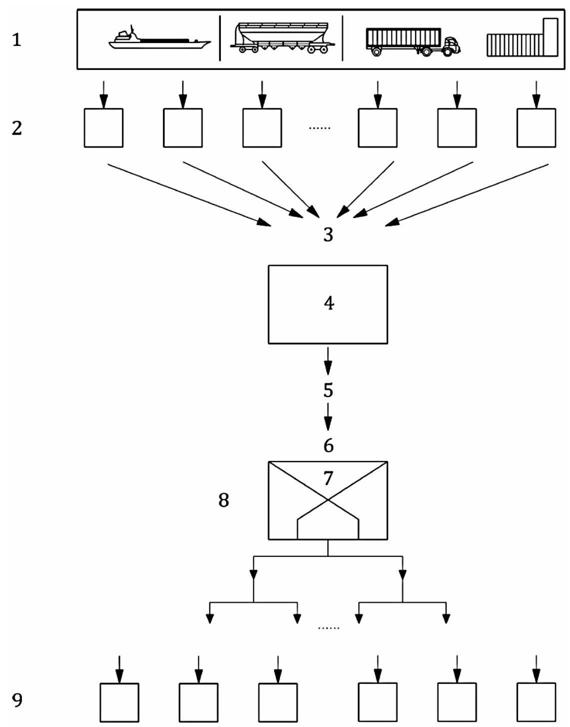


Fig. 2: Steps leading to the preparation of a laboratory sample [6].
Legend: 1 - lot; 2 - increments; 3 - merging of increments; 4 - aggregate sample; 5 - mixing; 6 - homogenization; 7 - divider; 8 - division; 9 - laboratory samples

2.2.5 Instruments and equipment

Various sampling instruments and devices are available. The appropriate equipment should be chosen based on the product being sampled, its quantity, and the containers used [5].

Mechanical sampling equipment should be designed with appropriate access points to allow for inspection, cleaning, maintenance, and repair of all parts that are subject to wear. These access points should be made of non-static materials [5].

The minimum acceptable dimension of the sampling device is three times the longest dimension of the largest particle. Below this threshold, the accuracy of the measurement is compromised due to the difficulty in selecting the particle size [7].

Examples of mechanical sampling devices used on flowing grain

This section outlines the various mechanical sampling devices used for flowing grains and provides illustrations of these devices.

1. **Cross-sectional sampling device** - Cross-sectional sampling devices allow for sampling across the entire cross-section of the falling grain flow. These devices can be open nozzle sampling devices (refer to Figure 3), tubular sampling devices with adjustable holes (refer to Figure 4), or tubular helical sampling devices (refer to Figure 5) [5].

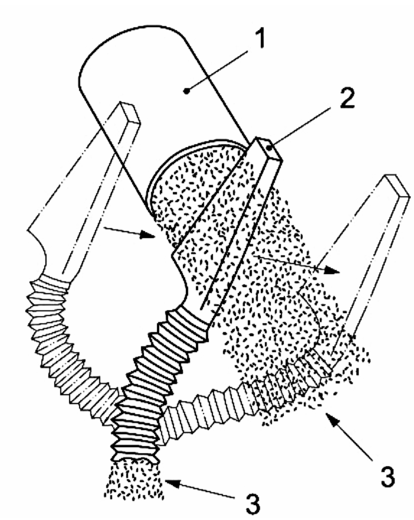


Fig. 3: Open nozzle cross-sectional sampling device for discontinuous repetitive sampling [5].

Legend: 1 - nozzle; 2 - sampler; 3 - grains

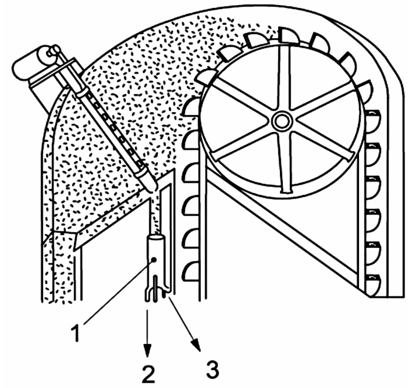


Fig. 4: Tubular cross-sectional sampling device with adjustable holes [5].
Legend: 1 - sample divider; 2 - sample flow; 3 - returning excess grain to the system

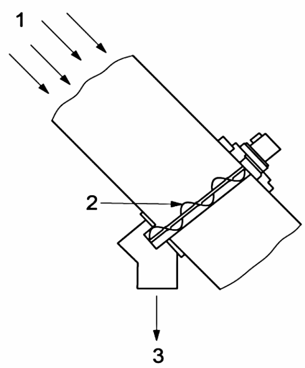


Fig. 5: Tubular helix sampling device [5].
Legend: 1 - grain flow; 2 - helix; 3 - sample flow

2. **Branch-type sampling device taking a sample from the main stream** - In a device of this type, the grain flow is intermittently diverted by means of a valve or shutter [5].

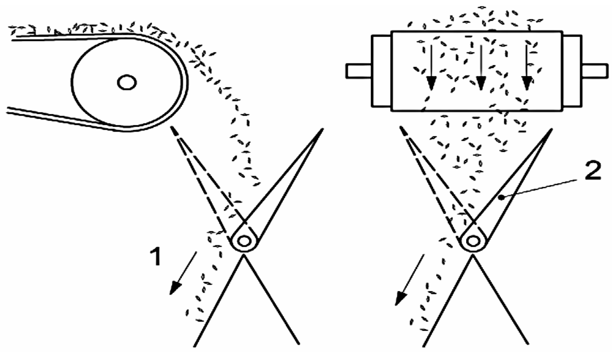


Fig. 6: A branch-type sampling device taking a sample from the main stream [5].
Legend: 1 - sample flow; 2 - flap or shutter

3. **Sampling device with a rotating container** - The grain stream in free-fall is sampled intermittently by a canister that rotates around a vertical central axis [5].

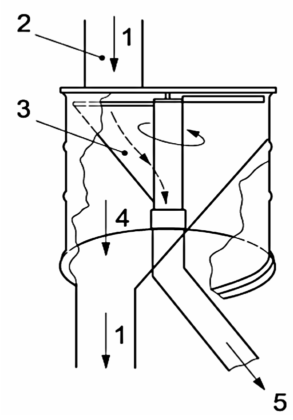


Fig. 7: Sampling device with a rotating container [5].
Legend: 1 - grain flow; 2 - vertical pipe; 3 - rotating container ; 4 - flow; 5 - sample flow

4. **Sampling device with bucket conveyor** - This device samples grains from a moving belt or conveyor. The containers move across the entire width of the grain stream thanks to side rolls that concentrate the grain on the belt. The samples are then conveyed to the hopper as the containers rotate around the upper cylinder [5].

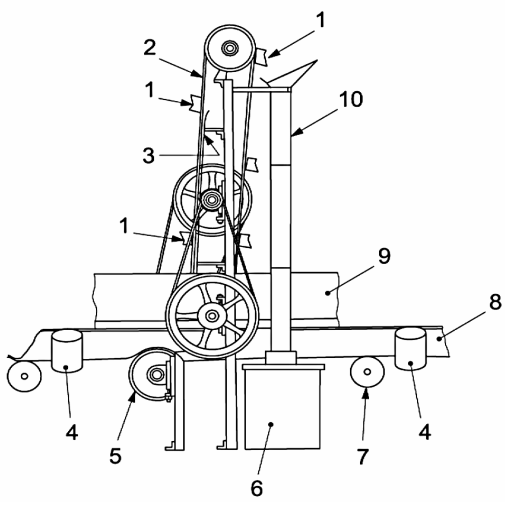


Fig. 8: Sampling device with bucket conveyor [5].
Legend: 1 - sample container; 2 - belt with sampling containers; 3 - belt driver; 4 - weight; 5 - special weight; 6 - sample tray; 7 - conveyor roller; 8 - carrier belt; 9 - protection panel; 10 - tray

Instruments for separating samples

This section outlines the various mechanical sampling devices used for flowing grains and provides illustrations of these devices.

1. **Parting irons**

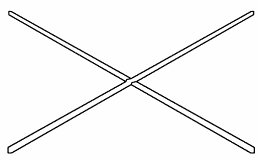


Fig. 9: Parting iron [5].

2. **Groove dividers (with baffles and plates)** - A medium-sized separator for cereal samples in the form of grains is required. The separator must have a minimum of 18 passes and a groove width of 12.7 mm [5].

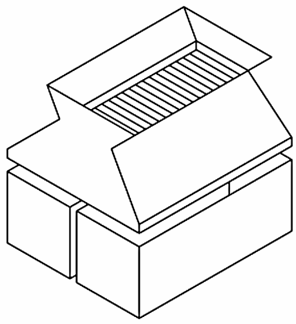


Fig. 10: Groove divider [5].

3. **Conical dividers (Boerner type)**

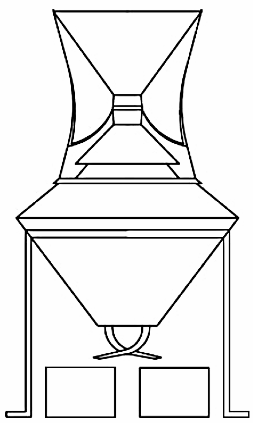


Fig. 11: Conical divider (Boerner type) [5].

4. **Rotary mechanical divider** - Enables the acquisition of multiple samples simultaneously [5].

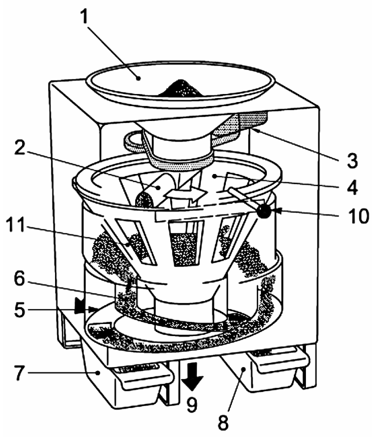


Fig. 12: Rotary mechanical divider [5].
Legend: 1 - hopper; 2 - rotating tube; 3 - engine; 4 - conical hopper with eight holes; 5 - collection of subsample; 6 - groove for collection of subsamples; 7,8 - two containers for collection of subsamples; 9 - flow of excess grain for return to the divider; 9 - automatic emptying of the collected sample ; 10 - setting the flaps to change the division factor; 11 - one of eight adjustable holes

2.2.6 Sampling errors

This section provides an overview of different sampling errors.

increment delimitation error (IDE) - occurs when the boundaries of an intended increment cannot be assured to be correct and identical to those for other increments. For one-dimensional sampling, an increment shall be delineated by parallel boundaries and shall provide a complete cross section of the moving flux of matter, i.e. covering both transverse dimensions (width, thickness). An IDE occurs when all parts of the lot do not have an exactly identical chance of becoming part of the sample. IDE is an increment delimitation problem [8]

increment extraction error (IEE) - occurs when the sampling tool is selective in what is extracted, thus failing to cover all parts of the delineated increments identically. Particles that hit the boundary wall of the increment tool must be forced to obey the centre-of-gravity rule. Particle centroids that fall within the boundaries of the delineated increment shall be included in the increment. Conversely, particle centroids that fall outside the boundaries of the delineated increment shall be excluded from the increment. The IEE is a problem of increment recovery or extraction [8]

increment preparation error (IPE) - post-sampling alterations resulting from contamination, losses, alteration (physical constitution or chemical composition), human errors, ignorance, carelessness, fraud or sabotage. IPE is not strictly speaking a sampling issue, as IPE effects only occur between or after sampling. However, there is good reason to categorise IPE with the other ISE as the resulting effects also add to TSE before analysis [8]

Increment weighting error (IWE) - occurs when the increments collected are not proportional to the contemporary flow rate (in one dimension) or to the thickness of a stratum (in two dimensions) at the time and place of collection [8]

2.2.7 Dynamic lots: Variographic analysis

Variographic analysis is an essential component of process sampling. The variogram of a one-dimensional measurement series (representing a 1-D lot) can be estimated either from historical data or from an active variographic experiment. It is often highly advantageous if a historical database exists, as this can be intelligently mined by problem-dependent variographic analysis. For a variographic experiment (variographic characterisation), N increments are typically collected using a systematic sample selection mode. The increments are initially treated as individual samples and subsequently analysed individually, resulting in a series of N analytical results. These results may subsequently be aggregated in various ways when they are used to simulate various optional composite sampling schemes. It is of the utmost importance that increments (samples) are sampled correctly. It is imperative not to induce IDE and/or IEE sampling errors, as illustrated in Figure 13, which is a principal illustration of increment outline traces across a conveyor belt (two correct delineations, and five incorrect). This figure outlines the parallel sides demand for the cutting tool trajectory. Identical rules apply to cross-cutting sampling of pipelines, where the traces shown represent 3-D slices [8].

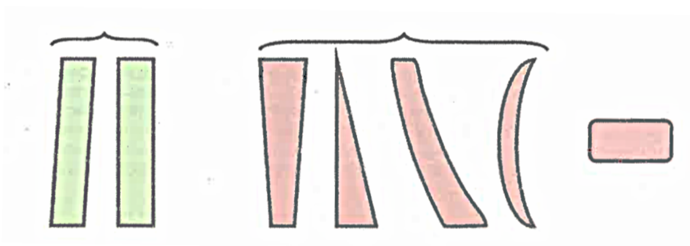


Fig. 13: Illustration of two correct and 5 incorrect sampling traces across flowing streams of matter [8].

The five rightmost increments will all result in a significant IDE (the rightmost trace represents an inappropriate grab sample). It should be noted that all examples may also be affected by IEE effects, or not, depending on the specific sampling and extraction process involved [8].

2.3 Industrial Communication Protocols

This section explains the protocols and connection strategies used in industrial communications, including examples of their use in the manufacturing industry. Together with a final comparison, the most common and widely used protocols in industry were selected [9].

2.3.1 Modbus

Modbus is an Industrial Control Protocol (ICP) used for transferring data between devices in automation and process control systems. The system follows a client/server model, allowing communication between devices connected across different types of buses or networks [10].

One device must be configured as a server and the other as a client to establish a Modbus connection. The client sends a request to the server, which responds by sending the requested information through a channel, by establishing a TCP/IP connection. This protocol uses different types of data messages to read or write information in compatible devices. Modbus RTU is one of the most commonly used methods of serial communication [10].

Modbus is known for its ability to connect with a wide range of devices and its high reliability in data transmission. Furthermore, as an open-source protocol, there are several high-level libraries available for various programming languages [10].

As an older industrial protocol, Modbus TCP has limited built-in security features. By default, it lacks encryption and authentication mechanisms, making it vulnerable to unauthorised access and data manipulation. To enhance security, the implementation of additional measures such as Virtual Private Networks (VPNs) and application layer encryption methods such as Transport Layer Security (TLS) or Secure Sockets Layer (SSL) can effectively protect Modbus TCP communications from potential threats [10].

In recent years, the Modbus Security Protocol was developed in 2018 as a result of efforts to improve the security of Modbus TCP. The focus of recent research is the strengthening of the security of Modbus TCP against unauthorised access [10].

Modbus is frequently used in the manufacturing industry to transfer data between devices, such as PLC and HMI (Human-Machine Interface), by utilizing sensors [10].

2.3.2 Profibus and Profinet

Profibus is an open field digital networking standard used to connect process automation components in industrial environments, such as field sensors, actuators and PLCs. Profibus architecture is based on a client/server model [10].

Profibus allows the server, acting as the process controller, to oversee communication with clients such as drivers, motors, I/O devices, and robots. To connect to a Profibus device, it is essential to have an operational and configured network, assign a device address and establish a communication channel with a Profibus server, such as a PLC or similar device. Devices can seamlessly exchange data and commands once connected [10].

However, as industrial networking requirements have evolved, Profibus has become obsolete compared to modern fieldbus protocols such as Modbus TCP, Ethernet/IP and Profinet. Profinet, an Ethernet-based fieldbus with an open and standardised architecture, offers significant advantages over its predecessor, including faster data transfer rates, greater flexibility and improved scalability. The migration from Profibus to Profinet has enabled industrial systems to take advantage of Ethernet-based communication, resulting in increased efficiency, enhanced interoperability and streamlined system integration. For reliable and efficient communication in industrial environments, Profinet has become the standard [10].

Profibus, being an older protocol, does not have native encryption and authentication mechanisms by default, which makes it vulnerable to security breaches. In contrast, Profinet provides advanced security features such as authentication through X.509 certificates and username/password, as well as encryption using TLS or Secure Real-Time Transport Protocol (SRTP). Profinet ensures data confidentiality and integrity. It provides robust protection against unauthorised access and data manipulation [10].

2.3.3 Ethernet/IP

Ethernet/IP is an ICP based on Ethernet technology that enables data to be transferred in real time between devices from different manufacturers and using different technologies. The system operates on a client/server architecture and is widely used in control applications in production plants that require the transmission of large amounts of high-speed data [10].

To implement Ethernet/IP, a common network must connect various devices, including sensors, actuators, and controllers, which communicate with each other to coordinate production operations. To achieve this, it is necessary to know the IP addresses and names of these devices and configure them to communicate at specific time intervals. A TCP/IP connection is then established with the device. This facilitates the exchange of I/O messages [10].

Ethernet/IP offers a number of benefits including high speed data transmission, scalability to integrate a wide range of devices and ease of configuration and troubleshooting. It is also easier to maintain because it is a standardised protocol [10].

Compared to Modbus TCP, Ethernet/IP offers more robust security features. To verify the identity of devices and users, it supports authentication mechanisms, including username and password-based authentication. In addition, Ethernet/IP supports IPSec (Internet Protocol Security), which provides confidentiality, integrity and authentication for IP-based communications. With the implementation of IPSec, data that is exchanged between devices can be encrypted for protection against unauthorised access [10].

2.3.4 OPC UA

OPC-UA is a cross-platform communication protocol designed for the secure and reliable exchange of data in the industrial automation sector. An OPC architecture comprises one or more OPC servers and OPC clients [10].

OPC-UA facilitates the continuous transfer of data between multiple devices and control applications, while imposing minimal restrictions on the data transfer process. It also serves as a means of communication between Supervisory Control and Data Acquisition (SCADA) applications and sensors. The use of bidirectional connections and persistent sessions is essential for the maintenance of active and uninterrupted communication between clients and servers. In terms of data capture frequency, OPC-UA is typically employed to monitor a reduced set of variables [10].

OPC-UA is currently the most prevalent communication protocol in Industry 4.0. It provides a multitude of benefits to its users, including high levels of security, the ability to transmit large amounts of data in real-time, and high scalability. Due to the protocol's technical independence, it can be used with a wide range of devices and operating systems produced by various manufacturers. However, implementing OPC-UA in complex and heterogeneous environments with numerous devices may present challenges in terms of cost and complexity [10].

OPC-UA was developed with security as a core design principle, offering a comprehensive suite of security features. It supports transport layer security protocols, including TLS/SSL, which provide encryption and authentication for secure data transmission. Additionally, OPC-UA incorporates robust access control mechanisms, allowing administrators to define detailed access policies for users and devices [10].

The multi-layered architecture of OPC UA provides a framework that is future-proof. New transport protocols, security algorithms, encoding standards, and application services can be integrated into OPC UA while ensuring backward compatibility with existing products [11].

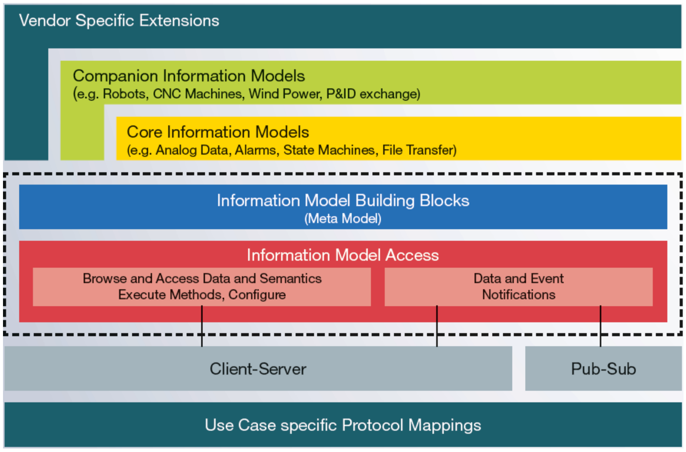


Fig. 14: UA-Architecture [11]

2.3.5 Protocol comparation

Table 1 compares the range, frequency, data rate and security of the five ICPs discussed above. The table shows that Modbus, Profibus, and Profinet protocols are suitable for local networks, while Ethernet/IP and OPC-UA are better suited for wide area networks, with OPC-UA having an unlimited transmission range. Ethernet/IP and Profinet have the highest frequency, which ranges from 1 to 100 MHz, and the highest data rate, which can reach speeds of up to 1 Gbps [10].

Tab. 1: Comparison of Industrial Communication Protocols [10]

Protocol	**Range**	**Frequency**	**Data Rate (Mbps)**	**Security**
Modbus	Local/Wide Area Networks	1-1000 Hz	Up to 0.1 Mbps	Low
Profibus	Local/Wide Area Networks	1-16 MHz	Up to 12 Mbps	Low
Profinet	Local/Wide Area Networks	1-100 MHz	Up to 1000 Mbps	High
Ethernet/IP	Wide Area Networks	1-100 MHz	Up to 1000 Mbps	Medium/High
OPC-UA	Unlimited	1-10 kHz	Up to 100 Mbps	High

When choosing an industrial protocol for a particular application, it is crucial to take into account factors such as network size, complexity, number of devices, and data transmission volume. These characteristics are crucial in determining the most suitable protocol for the given scenario [10].

The percentage usage of industrial protocols is shown in Figure 15 [10]. Industrial Ethernet accounted for 59% of newly installed nodes, while fieldbuses accounted for 35% of industrial usage. Ethernet/IP emerged as the dominant network, accounting for 15% of all installations, while Modbus TCP was used in 4% of cases. Among the fieldbuses, Profibus DP was the most widely used, accounting for 10% of the total. There was also a significant increase of 30% in the use of wireless technologies. This increase can be attributed to the rapid advancement of the IoT and the proliferation of mobile devices at the edge. The industry has recognised the many benefits of wireless communications, including improved mobility, flexibility and connectivity. This increasing adoption allows for real-time data transmission, remote monitoring, and control, resulting in enhanced operational efficiency and the development of novel applications [10].

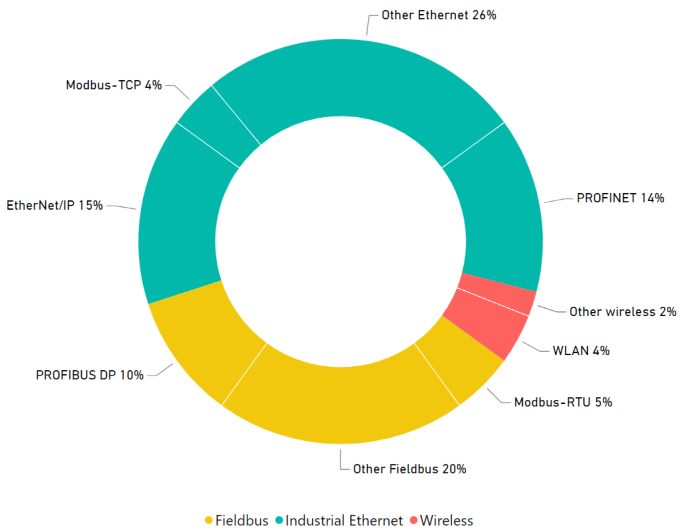


Fig. 15: Use of Industrial Communication Protocols [10]

Coding environments for industrial data collection

It is possible for practitioners to create bespoke methods for extracting data for machine tools using coding environments, rather than relying on off-the-shelf tools. Python is a widely used programming language and environment that offers a variety of libraries and tools for extracting data from industrial communication protocols [10].

The well-documented libraries for ICP in Python provide developers with efficient tools for extracting and processing data in big data environments. Python is highly favoured due to its simplicity, ease of use, and open-source nature, which offers the availability of libraries for various applications. However, Python's performance can be a drawback due to its nature as an interpreted language. Some Python environments may not achieve the same level of performance as compiled languages.

One potential solution to this issue is the use of environments such as Cython. This enables developers to create C extensions for Python, which can enhance the efficiency of computationally demanding operations [10].

2.4 Conveyor belts

The proposed development of the sample divider is based on a conveyor belt. This section will provide an overview of the characteristics, components and parts of conveyor belts.

2.4.1 Conveyor belts characteristics

A belt conveyor is a type of conveyor system that is used for the transportation of material from one location to another. Belt conveyors have a high load-carrying capacity, a large length of conveying path, a simple design, an easy maintenance process, and a high degree of reliability in operation. Belt conveyor systems are also used in material transport in foundry shops, such as for the supply and distribution of molding sand, molds, and the removal of waste [12].

In the initial stages of project design for the transportation of raw materials or finished products, the selection of the most cost-effective method for the volume of material to be moved, the plant and its maintenance, its flexibility for adaptation and its ability to carry a variety of loads, including the occasional overload, must be given priority [12].

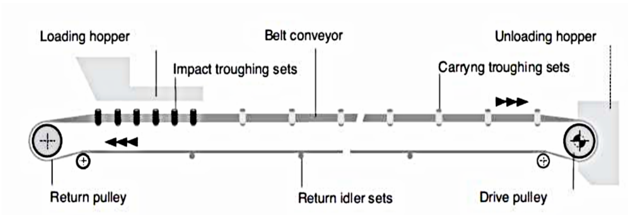


Fig. 16: Basic Drawing of a Belt Conveyor [12]

The design of the belt conveyor must commence with an assessment of the characteristics of the conveyed material, with particular attention paid to the angle of repose and the angle of surcharge. The angle of repose of a material, also known as the "angle of natural friction", is the angle at which the material, when heaped freely onto a horizontal surface, reaches the horizontal plane [12].

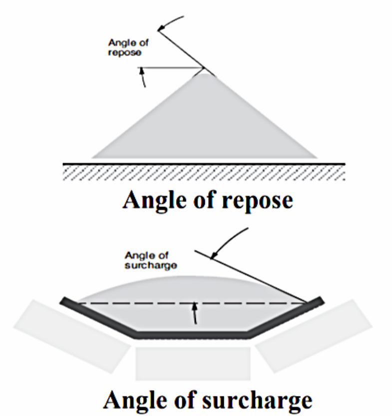


Fig. 17: Angles of Conveyed Material [12]

2.4.2 Components and parts of the conveyor belt

Understanding its critical components and operations can help with routine maintenance, repairs, upgrades and future system integrations. Each part plays an important role, and understanding the mechanical fundamentals can help you identify when continuous improvement situations occur within a conveyor system [13].

The conveyor belt is driven forward by a pulley system routed through a bed structure. The pulleys maintain the stability of the belt, ensuring that it remains tensioned, accurately tracked, has adequate traction, and is oriented in the correct direction. Each pulley within the conveyor belt structure serves a specific purpose based on its position within the system. Pulleys are primarily utilized in belted conveyors, although some manufacturers have developed chain-routed pulleys designed for live roller applications [13].

- **Tail end** – The tail pulley is situated at the loading end of the belt. It is available in two variants: a flat face or a slatted profile (wing pulley). The latter variant facilitates the cleaning of the belt by allowing material to fall between the support members [14].
- **Bend** – Pulley that directs the belt down to the take-up [13].
- **Take-up** – Situated lower than in the conveyor than the other pulleys, the take-up manages tension for the entire belt route [13].
- **Snub** – Increases traction and stability by providing angled tension to the head pulley [13].
- **Head** – The head pulley is situated at the discharge point of the conveyor. It is typically responsible for driving the conveyor and often has a larger diameter than other pulleys. In order to enhance traction, the head pulley is frequently lagged [14].

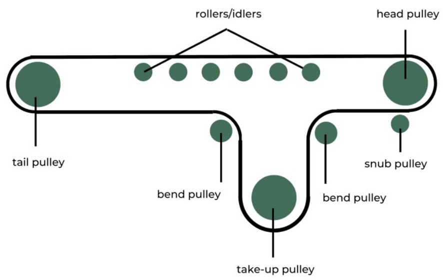


Fig. 18: Basic Conveyor Belt Pulley Routing [13]

The smooth operation of conveyor systems is contingent upon the functionality of bearings. These components serve as the mechanical interface between moving parts, providing support, reducing friction, and facilitating the motion of the conveyor belt. They are typically mounted on conveyor rollers, pulleys, and other rotating components, allowing them to rotate freely while minimizing wear and tear. Bearings enable the efficient and reliable movement of the conveyor belt, which in turn helps to transport materials smoothly and consistently. Properly functioning bearings are essential for preventing belt misalignment, reducing downtime, and extending the overall lifespan of the conveyor system. As a result of their crucial role in ensuring reliable and smooth conveyor operation, high-quality bearings are a key component in maintaining the performance and productivity of conveyor systems [13].

A gearbox represents a vital component in a conveyor system, fulfilling a mechanical role of power transmission. Its function is to regulate the speed and torque of the conveyor belt, which it achieves through a process of conversion of the rotational speeds and torques of the motor and the conveyor pulley or roller. A gearbox contains a set of gears with varying sizes and arrangements, which determines the gear ratio and consequently the output speed of the conveyor belt. The ratio can be modified according to the specific requirements of the conveyor system in order to provide precise control over the belt speed, direction, and performance. Gearboxes can be designed with different gear types [13].

2.4.3 Common tensioning methods

There are several commercial methods for providing and adjusting conveyor belt tension. Some of these methods comprise standard components that permit the user to design their own conveyor. Other methods are only available in designs that have been manufactured by conveyor manufacturers. Some of the most common tensioning methods are [15]:

Jack-Screw tension

Jack-screw tension is the most common belt tensioning mechanism. The tension on the belt is accomplished by turning the screw at the end of a conveyor. This pushes the bearing block towards the end of the conveyor, which adds tension to the belt. There is another, identical jack-screw located on the opposite side of the roller. The same procedure must be performed evenly for both rollers. In most conveyor installations, this tension mechanism is also used to adjust belt tracking [15].

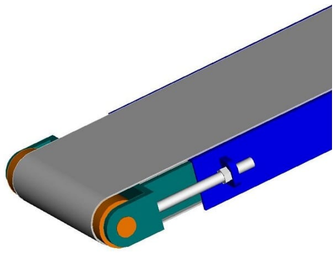


Fig. 19: Jack-Screw Tension [15]

Rack and pinion tension

The rack and pinion tensioning mechanism is achieved by incorporating a rack and pinion device into the conveyor frame. Two racks are mounted to the conveyor frame in a slide-able manner. The turning of the pinion shaft then exerts a force on the bearing blocks, which in turn moves the roller and adds belt tension. In general, the pinion runs the full width of the frame and contacts both racks, which ensures that the bearing blocks move evenly and parallel while turning from a single point. As the bearing blocks move in unison, an additional device is required for belt tracking. This may take the form of a jack screw or cam, which is typically mounted between the racks and the bearing block. The tensioning of the rack and pinion does not impede the tracking of the belt in the event that a belt tension adjustment is necessary [15].

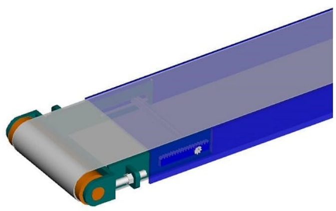


Fig. 20: Rack and Pinion Tension [15]

Tip-Up tail tension

The construction of a tip-up tail is achieved by the placement of the end roller of a conveyor on a pivot mechanism. This method of construction generally lifts the end roller above the conveyor frame. When the conveyor is placed in the lower-locked position, the total roller-to-roller length of the conveyor is longer than it is in the upper position. This extension provides tension to the conveyor belt. The pivot mechanism enables the entire end roller to move perpendicular to the conveyor frame, negating the need for access or adjustment from both sides of the frame. A tip-up tail mechanism does not provide the ability to adjust the belt tension to a specific value; it can only be set to a single position. Over time, as belts stretch, they will require adjustment. To accomplish this, a device such as a jack screw will need to be added for incremental tension adjustment. Furthermore, the jack screw can be employed for the purpose of belt tracking adjustment [15].

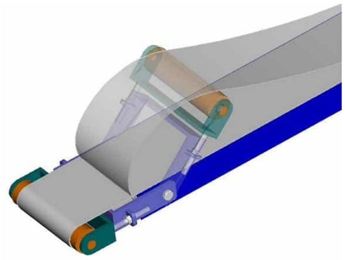


Fig. 21: Tip-Up Tail Tension [15]

Pneumatic or spring tension

Pneumatic or spring tension is typically employed on conveyors that are subjected to heavy loads or operate over longer distances. This is achieved by the addition of at least three rollers to the underside of the conveyor. Belt tension is generated by connecting a pneumatic cylinder or a spring-loaded device to the lower tension roller. The cylinder exerts a downward force on the lower roller, thereby applying tension to the belt. Typically, a single cylinder is connected to the ends of the roller via a cross bracket. The cylinder will move the ends of the roller in an even and parallel manner. One advantage of this mechanism is that it automatically compensates for belt stretch. Belt tracking is typically accomplished by adding a device such as a jack screw to the snub rollers just above the tension roller [15].

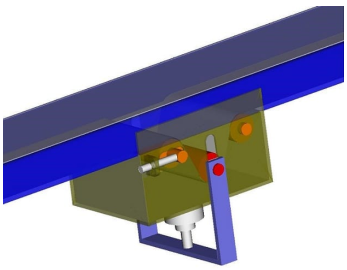


Fig. 22: Pneumatic or Spring Tension [15]

2.5 Electric circuit

In order to develop an automatically adjustable sample divider, it is necessary to establish an electrical circuit. This section will provide a brief overview of the parallel circuits and capacitors, outlining their characteristics and advantages.

2.5.1 Parallel circuits

A circuit is defined as a parallel circuit when all the devices are connected using parallel connections. In a parallel circuit, each device is placed in its own separate branch. The presence of branch lines indicates that there are multiple pathways by which charge can traverse the external circuit. Each charge passing through the loop of the external circuit will pass through a single resistor present in a single branch. Upon reaching the branching point, a charge must select the branch through which it will return to the low potential terminal [16].

The most significant properties of parallel circuits are that the total voltage of a parallel circuit is equal to the voltage across each branch, and that the total current in a parallel circuit is the sum of the individual branch currents. Furthermore, the net resistance of a parallel circuit is always less than any of the individual resistance values [17].

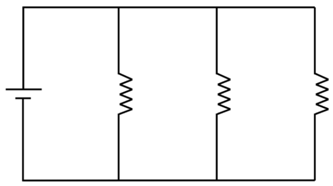


Fig. 23: Parallel Circuit [17]

2.5.2 Capacitors

A capacitor is a device that stores electric charges. It is used for maintaining a constant voltage, reducing noise and fluctuations in the circuit. When a high voltage is applied to a parallel circuit, the capacitor is charged. Conversely, it is discharged with the application of a low voltage. When capacitors are placed in parallel with one another, the total capacitance is simply the sum of all capacitances [18].

2.6 Journal of open hardware

The Journal of Open Hardware (JOH) is a peer-reviewed open access publication for open hardware research and development. The journal's primary objective is to facilitate the integration of academic disciplines that contribute to open practices of design, fabrication, and dissemination of research instruments, as well as the multiple dynamics that shape these processes. JOH encompasses technical, legal, scientific, educational, economic, and sociocultural aspects of hardware. The members of JOH extend an invitation to submissions from a diverse range of fields, including but not limited to human-machine interaction, biotechnology, engineering, physics, computer science, the humanities, and the social sciences [19].

2.7 Components supplied by JKI

This section provides an overview of the components supplied by JKI, including their specifications and characteristics. The mechanical components will be presented first, followed by the electrical ones.

2.7.1 Food belt

The food belt is employed in a variety of settings, including agriculture and the transportation of paper, rubber, tires, and other materials. Additionally, it is suitable for use with foodstuffs, as it meets the standards set by the Food and Drug Administration (FDA) for food contact surfaces. It is designed to run on sliding tables or rollers. The fabric is made of polyester, the smooth side (carrying side) is made of Flexam PVC, and the slippery side (running side) is also made of fabric [20].

Fig. 24: Food Belt [21]

Tab. 2: Specifications of Food Belt [22]

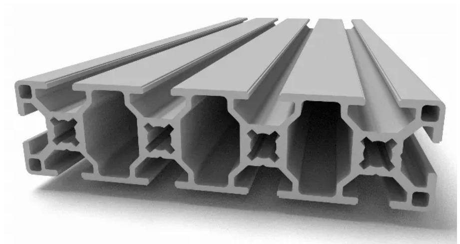
Belt thickness	1.90 mm
Weight	2.10 kg/ m^2
Temperature range	-15 °C to 80 °C
Minimum pulley diameter	50.0 mm
Width	100.0 mm

2.7.2 Aluminum construction profiles

Aluminium construction profiles are employed in the construction of machine frames, workstations, shelves and guarding structures. Additionally, robust and versatile aluminium system profiles are utilised in the fabrication of test set-ups, exhibit constructions and load-bearing structures.

The construction profiles supplied by JKI were of varying lengths (Figure 25a). One B-type profile was provided for the support of the food belt (Figure 25b). As this profile provides a highly smooth surface, it allows the belt to slide with minimal friction, thereby reducing the potential for friction-related wear and tear.

(a) Different Lengths of Profiles



(b) B-type Profile

Fig. 25: Aluminium Construction Profiles

2.7.3 Arduino Mega 2560

The Arduino Mega 2560 is a microcontroller board based on the ATmega2560. It has 54 digital input/output pins (of which 15 can be used as PWM outputs), 16 analog inputs, 4 UARTs (hardware serial ports), a 16 MHz crystal oscillator, a USB connection, a power jack, an ICSP header, and a reset button [23].

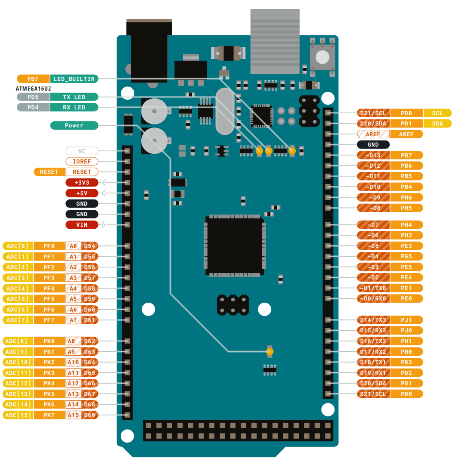


Fig. 26: Arduino Mega 2560 Schematics [23]

Tab. 3: Arduino Mega 2560 Recommended Operating Conditions [23]

Symbol	Description	Min	Typ	Max	Unit
V_{IN}	Input voltage from VIN pad / DC Jack	7	7.0	12	V
V_{USB}	Input voltage from USB connector	4.8	5.0	5.5	V
T_{OP}	Operating Temperature	-40	25	85	°C

2.7.4 Stepper motor 23HS6620B

A stepper motor is an electric motor that rotates its shaft by performing steps, that is, by moving a fixed amount of degrees. This feature is obtained thanks to the internal structure of the motor, which allows the angular position of the shaft to be known with precision by simply counting the number of steps performed. This feature also makes the motor suitable for a wide range of applications [24].

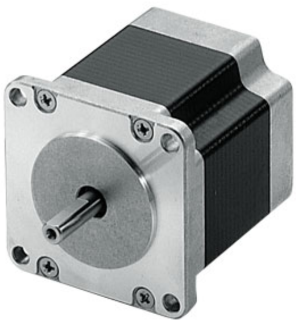


Fig. 27: Stepper Motor 23HS6620B [25]

Tab. 4: Specifications of 23HS6620B Stepper Motor [22]

Motor type	Nema23 Hyprid stepper motor
Step angle	1.8 °
Rated voltage	2.7 V
Rated current	2.0 A
Phase resistance	1.35 Ω
Phase inductance	2.5 mH
Holding torque	0.9 N.m
Shaft diameter	6.35 mm

2.8 Motor driver DRV8825

The DRV8825 provides an integrated motor driver solution for printers, scanners, and other automated equipment applications. The device comprises two H-bridge drivers and a microstepping indexer, and is intended to drive a bipolar stepper motor.

The output driver block consists of N-channel power MOSFETs configured as full H-bridges to drive the motor windings. The DRV8825 is capable of driving up to 2.5 A of current from each output (with proper heat sinking, at 24 V and 25 deg C). A simple STEP/DIR interface allows for straightforward interfacing with controller circuits. Mode pins facilitate configuration of the motor in full-step up to 1/32-step modes. The device is configurable to enable the use of slow, fast or mixed decay modes. A low-power sleep mode is provided, which shuts down internal circuitry to achieve a very low quiescent current draw. This sleep mode can be set using a dedicated nSLEEP pin. In addition, the device incorporates internal shutdown functions for overcurrent, short circuit, under voltage lockout and over temperature. Fault conditions are indicated via the nFAULT pin [26].

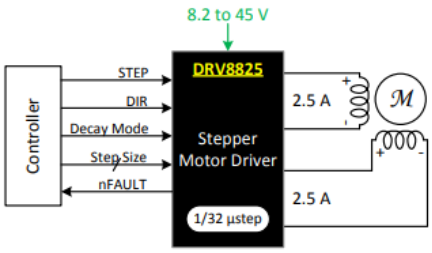


Fig. 28: Motor Driver DRV8825 [26]

2.9 Servo motor MG996R

A servo motor is defined as an electric motor that allows precise control of angular or linear position, speed and torque. It consists of a suitable motor coupled to a sensor for position feedback and a controller that regulates the movement of the motor according to a desired setpoint. Servo motors are essential in industries such as robotics, CNC machines and automated manufacturing due to their precision, fast response and smooth motion [27].

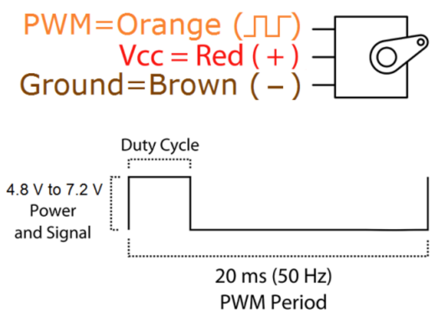


Fig. 29: MG996R PWM Period [28]

Tab. 5: Specifications of the MG996R Servo Motor [28]

Rotation	120 degrees
Dimension	40.7 x 19.7 x 42.9 mm
Stall torque	9.4 kgf · cm (4.8 V), 11 kgf · cm (6 V)
Operating speed	0.17 s/60º (4.8 V), 0.14 s/60º (6 V)
Operating voltage	4.8 V to 7.2 V
Running Current	500 - 900 mA (6 V)
Temperature range	0 ºC – 55 ºC

2.10 Voltage regulator S13V30F5

A voltage regulator is a circuit that generates and maintains a constant output voltage, regardless of fluctuations in the input voltage or load conditions [29].

Fig. 30: S13V30F5 Voltage Regulator [30]

Tab. 6: S13V30F5 Specifications [30]

Parameter	**Specification**
Minimum operating voltage	2.8 V
Maximum operating voltage	22 V
Continuous output current	3 A
Output voltage	5 V
Reverse voltage protection?	Yes
Maximum quiescent current	100 mA
Output type	Fixed 5V

This section outlined the characteristics and specifications of components supplied by JKI. These components are employed for the sample divider as they provide the requisite characteristics for the smooth operation of the sample divider.

3 SOLUTION

The design and implementation of an automatically adjustable sample divider with a mini conveyor belt necessitates a multifaceted approach that addresses mechanical, software and electrical requirements. This section presents a comprehensive overview of the solution, divided into three distinct sections. Firstly, the mechanical design focuses on the physical construction and functionality of the sample divider, including the design of the conveyor system, material handling mechanisms and component integration. As the design of the construction part should be suitable for publication in Journals of open hardware, it was necessary to use a free software CAD program, specifically FreeCAD. The majority of the developed mechanical components were manufactured using 3D printing technology, with materials such as PLA and PETG, as both materials produce high-quality prints with smooth finishes. The second section of the solution chapter outlines the software implementation, including the development of the sampling algorithm, the design of the communication between the software and the components of the mechanical part, and the implementation of the industrial communication protocol. Finally, the third section focuses on the integration of the electrical system. As the objective is to develop an automatically adjustable sample divider at an affordable cost, the solution will not comprise any sensors. The solution for the electrical part encompasses the integration of motors, drivers, and microcontrollers, as well as the configuration of power management systems to ensure the efficient and reliable operation of the sample divider.

3.1 Mechanical design

The development of the sample divider is based on the branch-type sampling device, as this type of device is based on sampling with a flap from a grain flow. This technique of sampling is easily implemented with the proposed design of the sample divider based on a conveyor belt.

This section will provide a comprehensive account of the development and design choices of the mechanical components of the sample divider. For the purpose of facilitating orientation, simplified schematics of the front (Figure 31) and top views (Figure 32) of the sample divider are provided. The dimensions of all developed components, together with the main dimensions of the construction frame ($0.95 \times 0.83 \times 0.45\,\text{m}$), are provided within the CAD files in the electronic appendix of this thesis.

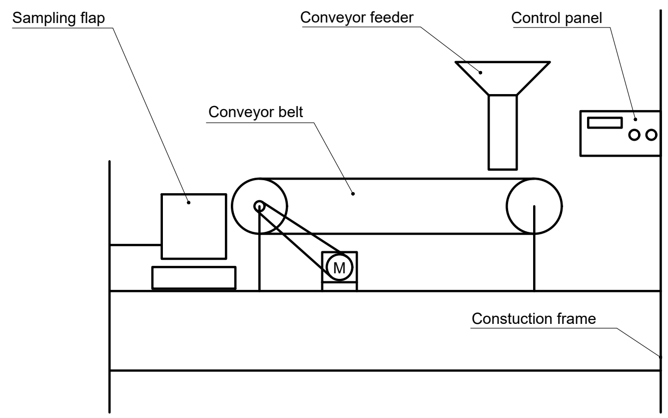


Fig. 31: Front view of simplified schematic of sample divider.

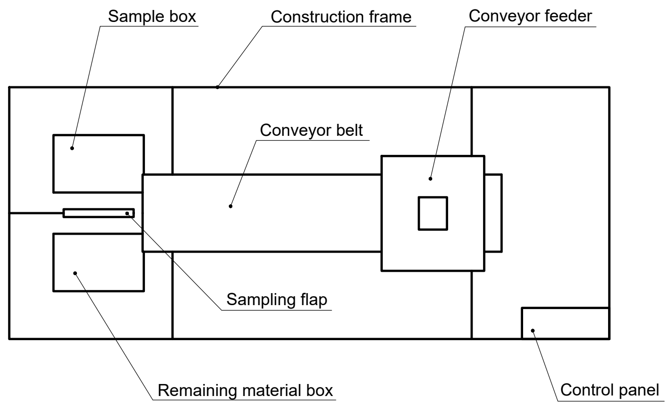


Fig. 32: Top view of simplified schematic of sample divider.

3.1.1 Construction frame

The construction frame serves as a support for the other mechanical parts, including the sampling flap, conveyor belt, conveyor feeder, control panel, motors, and boxes for seeds. The construction frame was constructed using aluminium profiles supplied by JKI. The length of individual profiles was adjusted by slicing. The precise configuration of individual profiles was arranged in a way that the other mechanical components are firmly and immovably attached and placed in the right position. The individual profiles were connected by bolts and nuts.

Fig. 33: Base Construction Frame for the Conveyor Belt

3.1.2 Conveyor belt

The primary component utilised for the conveyor belt was a food belt supplied by JKI. This food belt is ideal for the sample divider, as it is suitable for the transportation of foodstuffs such as seeds and the belt material can be easily cleaned to avoid cross-contamination. Table 2 specifies that the minimum pulley diameter is 50 mm and the width 100 mm. Consequently, the pulleys were designed to fit these dimensions and manufactured using 3D printing technology.

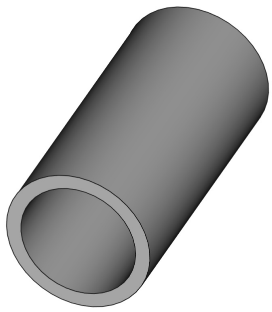


Fig. 34: Pulley Design

In order to prevent the belt from shifting or slipping off the pulleys, which could lead to operational disruptions or damage to the belt, custom covers for the pulleys were also manufactured using 3D printing technology. These covers fit snugly inside the pulleys and have an outer diameter that is slightly larger than that of the pulleys, thus securing the belt in place and preventing it from falling off. The connection between the pulleys and covers is achieved through a press fit, which is why the pulley cover has a small chamfer on the fitting diameter. This facilitates the fitting process.

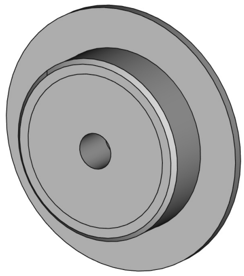
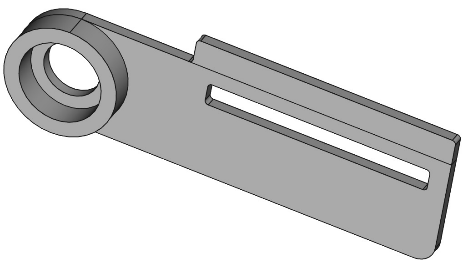


Fig. 35: Pulley Cover Design

The efficiency of the conveyor system is contingent upon the precise and smooth rotation of the pulleys. This is achieved through an assembly comprising steel shafts and radial ball bearings housed in custom 3D-printed components.

The steel shaft is characterised by its strength and durability, which are crucial for bearing the rotational forces and loads exerted during operation. Furthermore, the shaft has a very smooth surface finish, which is essential for the easy positioning and sliding of the bearings on the shafts.

The radial ball bearings are housed in custom frames by a force fit, thereby ensuring a highly secure connection. The frames were manufactured using 3D printing technology. The shape was designed in such a way that it can be mounted to the B-type profile, which is used to support the food belt.



(a) Frame Design

(b) Ball Bearing

Fig. 36: Bearing Seating

To address the issue of axial displacement (a condition where components move along the axis of rotation, potentially leading to operational instability or failure), custom 3D-printed rings were developed to secure the pulleys against axial movement. The rings exert a frictional force on the shaft, effectively preventing any axial movement. The effectiveness of this solution depends on the contact area between the shaft and the ring, and the press fit.

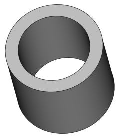


Fig. 37: Ring Design

The aforementioned components collectively constitute the front section of the conveyor belt.

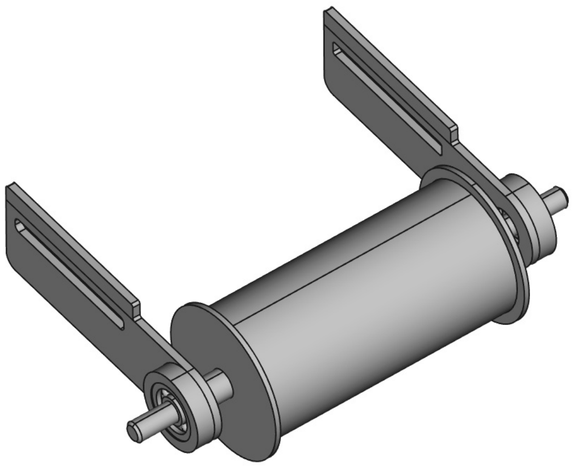


Fig. 38: Front Section of the Conveyor Belt

Tensioning mechanism

In order to guarantee the smooth operation and accurate tracking of the conveyor belt, it is essential to implement an appropriate tensioning mechanism. This involves adjusting the tensioning mechanisms to achieve the desired tension level, which is of paramount importance for minimising belt sag, preventing slippage, and ensuring efficient material handling.

The tensioning mechanism, which employs the Jack-Screw tension method, was selected for its straightforward and efficacious design and ease of implementation. Tightening the nut causes the bolt to move along the conveyor belt, thereby tensioning the belt.

Given the considerable forces exerted during the tightening process, the components are reinforced to withstand such pressures.

(a) Bolt Head Closure (b) Bolt Head Fit

Fig. 39: Components for Mounting the Bolt Head

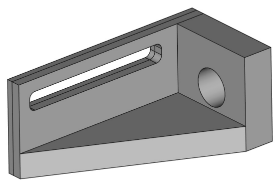


Fig. 40: Component for Tightening the Nut

The following figure illustrates the mounting of the tensioning mechanism.

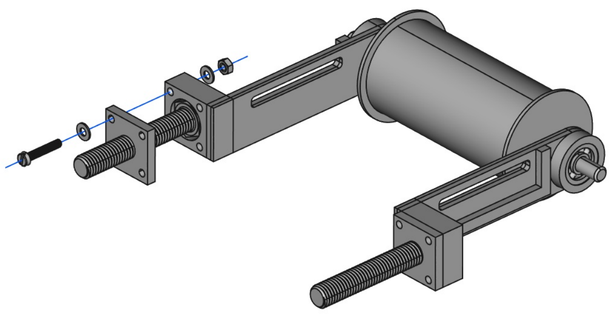


Fig. 41: Mounting the Tensioning Mechanism

The aforementioned components collectively constitute the rear section of the conveyor belt.

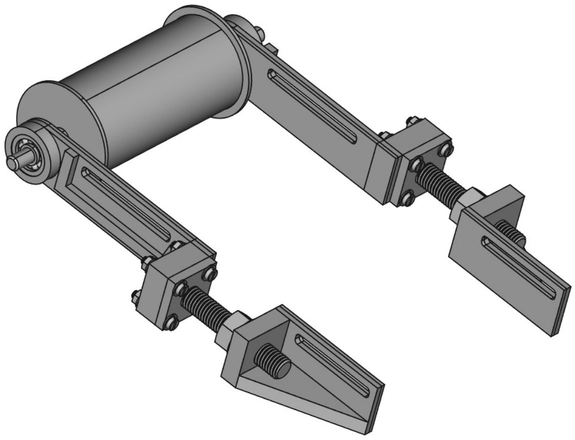


Fig. 42: Rear Section of the Conveyor Belt

In order to provide support for the food belt, the B-type aluminium profile supplied by JKI was utilised. The profile has dimensions that align with the requirements of the belt, and a low-friction surface, which enables the belt to slide smoothly.

The assembly of the front and rear sections to the support of the food belt results in the formation of the conveyor belt.

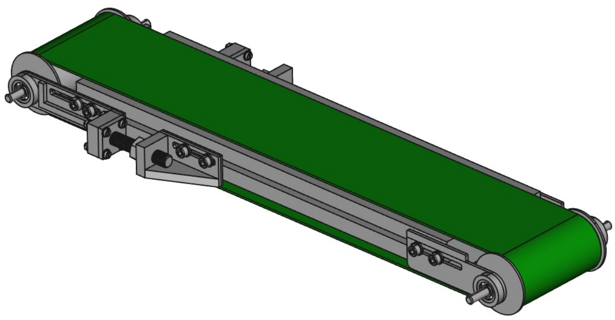


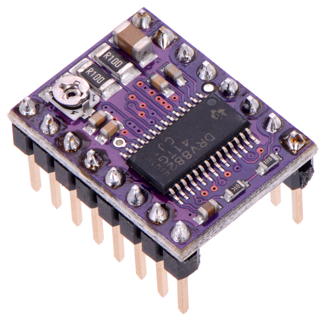
Fig. 43: Conveyor Belt

Conveyor belt motor

The motor that drives the conveyor belt is the stepper motor 23HS6620B, supplied by JKI. This motor divides a full rotation into a number of equal steps, which is required for accurate positioning of the conveyor belt.

A DRV8825 motor driver, supplied by JKI, was employed to regulate the stepper motor effectively. This driver module enables precise control of the motor's speed and direction, allowing adjustments to be made to the conveyor's movement. The DRV8825 is specifically designed to manage the complex current requirements of stepper motors, ensuring efficient and stable operation.

(a) Stepper Motor [25]



(b) Motor Driver [31]

Fig. 44: Conveyor Belt Motor

Due to the conveyor belt's stiffness, which places significant demands on the performance of the stepper motor, the transmission belt and pulleys were embedded in the solution. The utilisation of a smaller pulley mounted on the shaft of the stepper motor to drive a larger pulley mounted on the front shaft of the conveyor belt results in an increase in torque but a decrease in speed. The specific gear ratio of 3, provided sufficient transmission to address the issue with conveyor belt stiffness.

Fig. 45: Belt Gear [32]

3.1.3 Sampling flap

The sampling flap is employed for the division of the material into a sample box, which contains the final sample, and the remaining material box. The dimensions of the flap must be sufficiently large to enable the capture of every piece of material at the end of the conveyor belt, which is why the part of the flap is situated beneath the conveyor belt. The optimal position for the flap is at the end of the belt, at a height that is as close as possible to that of the belt. This configuration minimises the impact of material particles rebounding off the flap. The rotation of the flap is controlled by a servo motor, MG996R, supplied by JKI.

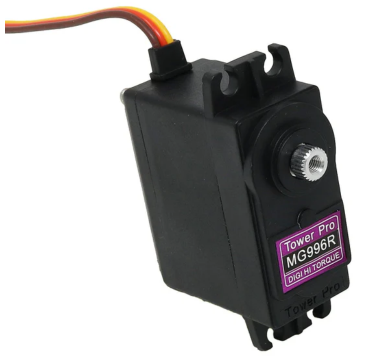
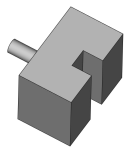
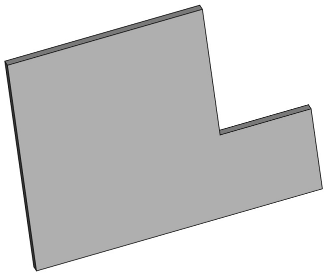


Fig. 46: Servo Motor MG996R [33]

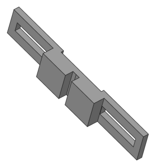
The servo motor is connected to the flap by a connecting component on one side, while the other side is connected through another connecting component to the joint, allowing for free rotation.



(a) Joint Attachment



(b) Sampling Flap



(c) Servo Attachment

Fig. 47: Sampling Flap Components

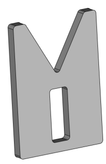


Fig. 48: Joint for Free Rotation of Sampling Flap

The subsequent illustration depicts the mounting of the sampling flap to the servo motor and joint.

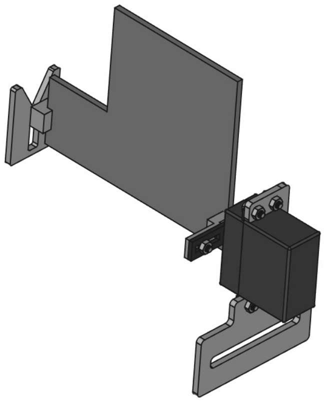
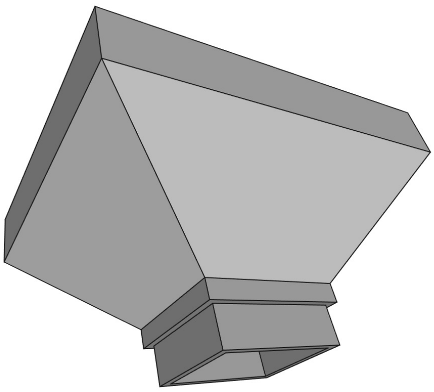


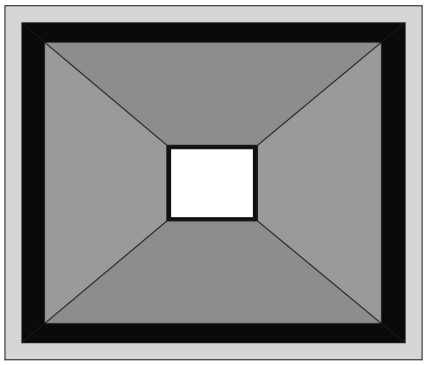
Fig. 49: Mounting of the Sampling Flap to the Servo and Joint

3.1.4 Conveyor feeders

Conveyor feeders are employed to convey material on the conveyor belt. Initially, the material must be manually filled into the hopper. The top of the hopper is designed with the largest dimensions, facilitating the filling of material. The dimensions then gradually decrease until they reach the dimensions of the feeding mechanism.



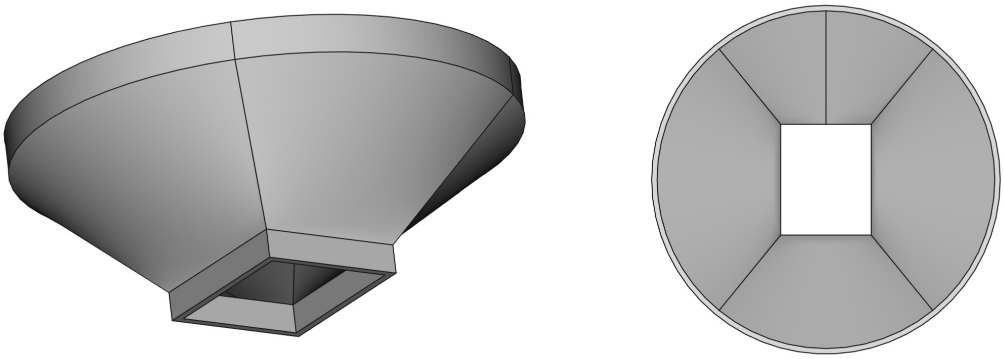
(a) Hopper



(b) Top View

Fig. 50: Hopper Design

The dimensions of the hopper are sufficient for the testing of the sample divider. However, in order to accommodate a total volume of 2 litres, an additional hopper of a larger size was designed and constructed, with the capability of being connected to the smaller hopper. This enables the system to meet the specified requirement.



(a) Additional Hopper (b) Top View

Fig. 51: Additional Hopper Design

The subsequent illustration depicts the two hoppers in a connected configuration.

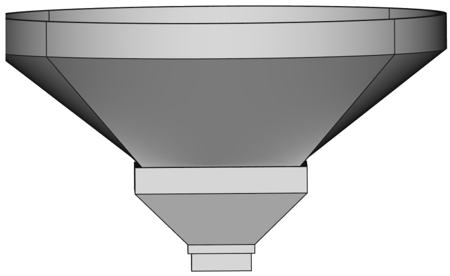
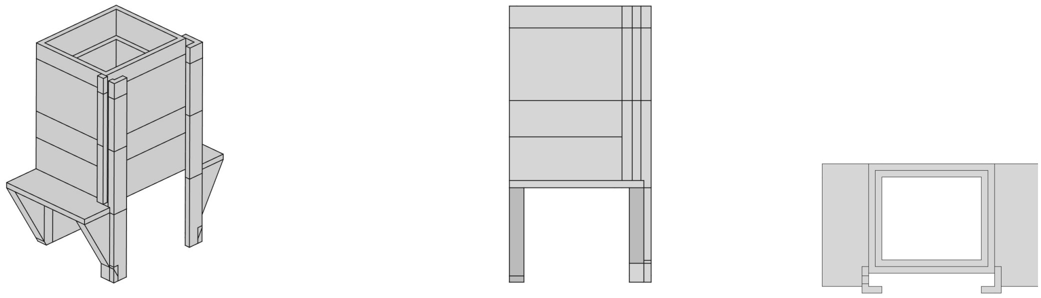


Fig. 52: Hoppers in a Connected Configuration

The hopper is then connected to the feeding mechanism. The purpose of these feeding mechanisms is to produce a minimal cross-section of a continuous stream of material. Since different particles of material have different shapes and sizes, achieving the minimum cross-section of a continuous material stream is challenging. To address this, different versions of feeding mechanisms were developed. These feeding mechanisms can be easily attached and detached, allowing for the testing of different types. A total of four versions of the feeding mechanism were developed, designated A, B, C, and D.

Version A

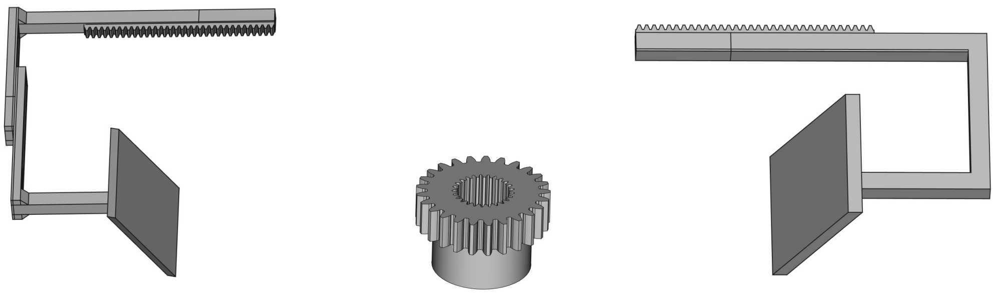
The objective of this version is to create a narrowest continuous stream of material possible within the feeding mechanism.



(a) Version A (b) Side View (c) Top View

Fig. 53: Version A Design

In order to achieve the desired width of the stream of particles of varying sizes and shapes, an adjustable mechanism comprising of adjustable side doors was developed.



(a) Left Door (b) Gear Wheel (c) Right Door

Fig. 54: Adjustable Side Door Components

The left door's arm is composed of two parts, allowing for an adjustable length, which is crucial for achieving the correct position of the arm with respect to the position of the gear wheel. The gear wheel comprises an external and internal involute gear. The internal gear matches the module of the MG996R servo motor gear to which it will be connected. The external gear is designed to match the module of the involute racks, which are the components of the left and right arms with a module of 0.5 mm. This size of the module was selected to provide an appropriate degree of control for the movement of the adjustable side doors.

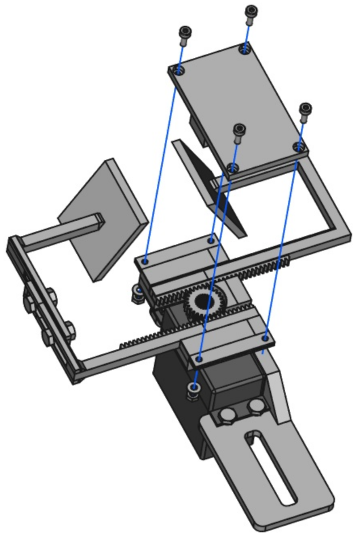


Fig. 55: Adjustable Side Door Mechanism Assembly

In order to guarantee the optimal functioning of the adjustable side doors, a structure was developed to support both arms. This structure serves to maintain the height of the side arm, thereby ensuring its proper operation.

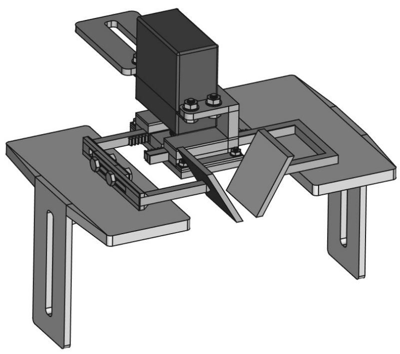


Fig. 56: Support Structure for the Side Arms

In order to regulate the height of the material stream, an adjustable front door was developed. This consists of an involute rack on the side of the door with a module of 0.5 mm, which matches the module of the MG996R servo motor gear. By turning the servo motor, the front door changes the opening size of the conveyor feeder, thus controlling the height of the material stream. To prevent material particles from becoming stuck inside the conveyor feeder, a different material with a different stiffness was glued to the front door. This material is then in contact with the material.

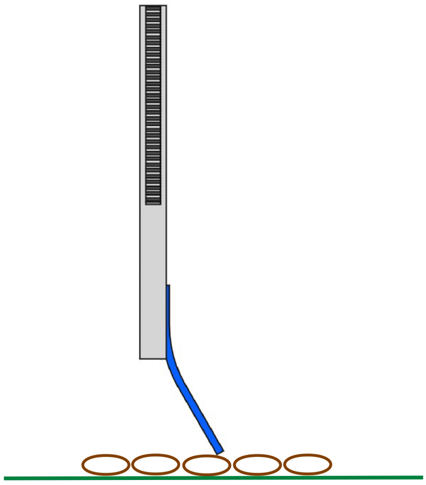
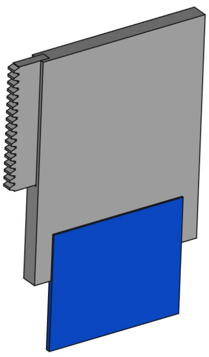
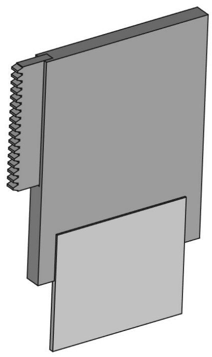


Fig. 57: Behaviour of the Bonded Material

Two front doors were developed, each with a distinct material bonded by glue. One door was constructed with rubber material, while the other was constructed with foil material. Both materials exhibited varying degrees of stiffness, with the foil material exhibiting greater stiffness.



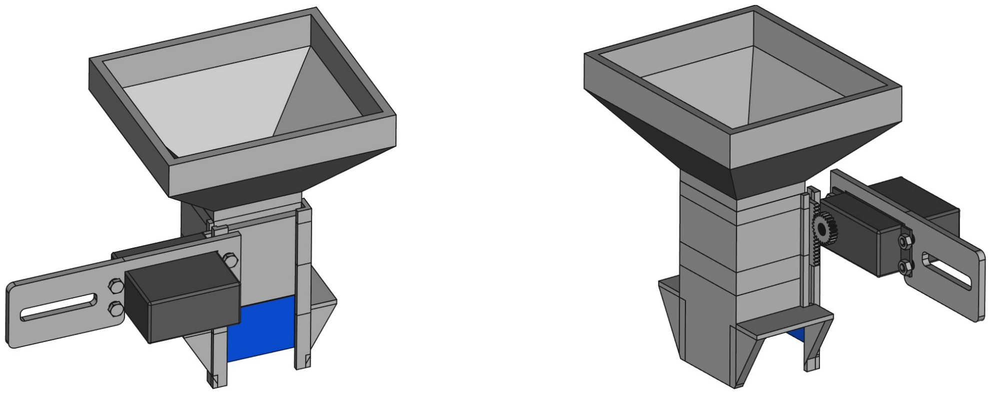
(a) Rubber Material



(b) Foil Material

Fig. 58: Front Doors with Different Bonded Materials

The subsequent illustration depicts the operation of the servo motor in controlling the front door.



(a) Front View

(b) Rear View

Fig. 59: Front Doors Controll

The collective movement of the adjustable front and side doors allows for the formation of a desired cross-section of the material stream.

The feeding mechanism is positioned as close as possible to the conveyor belt, allowing the belt to grasp the particles from the feeding mechanism.

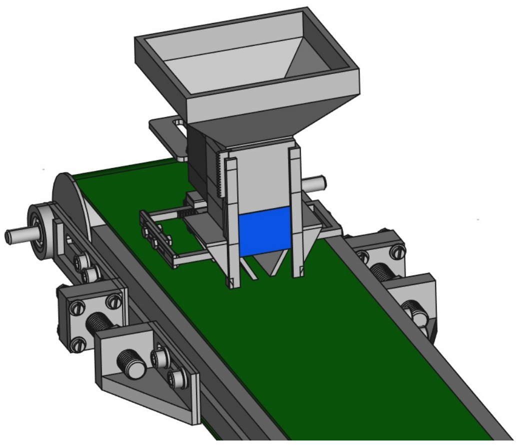
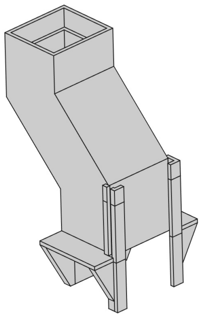


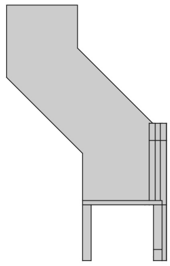
Fig. 60: Version A on a Conveyor Belt

Version B

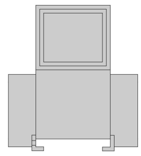
In version A, particles are arranged in a stacked configuration within the conveyor feeder. This results in considerable pressure being exerted on particles in close proximity to the conveyor belt. To address this issue, a new design was developed to reduce this pressure by beveling the feeding mechanism by 45 degrees. The specific angle was chosen as a compromise between the pressure exerted on the particles near the conveyor belt and the ability of the particles to slide down the feeding mechanism. Furthermore, the mechanism remains identical to that of version A.



(a) Version B



(b) Side View



(c) Top View

Fig. 61: Version B Design

The following illustration depicts the version B of the conveyor feeder on a conveyor belt.

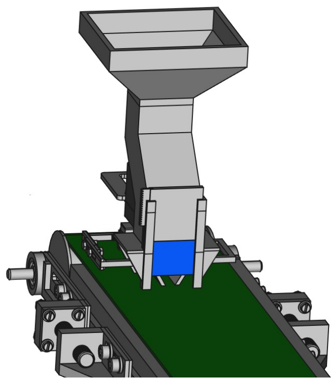
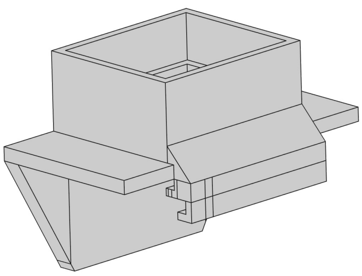


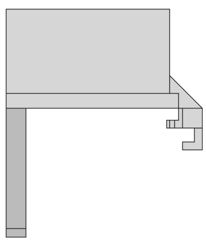
Fig. 62: Version B on a Conveyor Belt

Version C

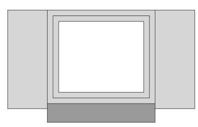
The principal objective of this design is to create the narrowest continuous stream of material possible outside the feeding mechanism.



(a) Version C



(b) Side View



(c) Top View

Fig. 63: Version C Design

As the material stream is created outside the feeding mechanism on the conveyor belt, it is crucial to prevent material particles from falling off and to maintain the desired width of the material stream by preventing rounded particles from rolling off the belt. To address these challenges, a custom rails were developed. The rails comprise of two joints, allowing for manual adjustment of the width and angle of the material stream. The arms of the rails were constructed from aluminium profiles, while the rails themselves were manufactured from sheet metal. The smooth surface of the sheet metal allows the material stream to flow smoothly, and the rail material is also easy to clean, which is necessary to avoid any cross-contamination.

Fig. 64: Custom Rails

This version of the feeding mechanism employs the same control of the side doors by servo motor as previous versions, with the exception of the design of the side doors. The front and side doors have been integrated into a single unit. The particles fall down the feeding mechanism through the gap, which is regulated in size by the servo motor. Subsequently, the particles are aligned to the desired cross-section by the shape of the adjustable doors, theoretically achieving a cross-section of a triangle.

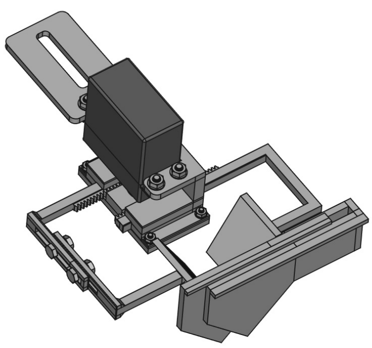
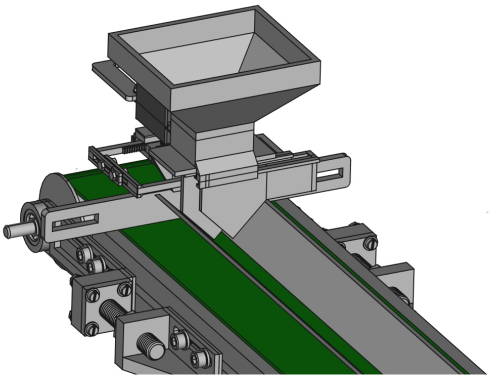
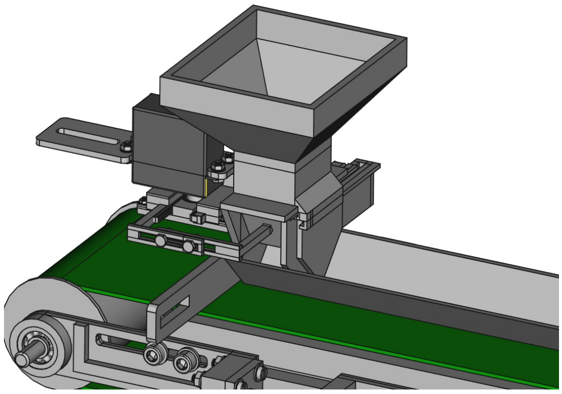


Fig. 65: New Design of the Side Doors

The following illustration depicts the version C of the conveyor feeder on a conveyor belt, as well as a side view to demonstrate that the feeding mechanism is situated above the conveyor belt and that the material stream is created outside the feeding mechanism on the conveyor belt. In order to ensure that the material particles remain on the belt, rails have been added to the conveyor belt.



(a) Front View

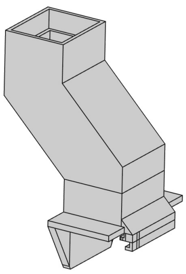


(b) Side View

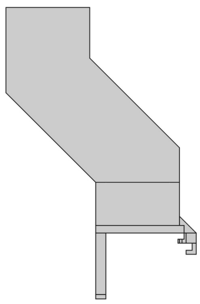
Fig. 66: Version B on a Conveyor Belt

Version D

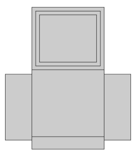
The concept is analogous to that of version B, whereby a smaller pressure is applied to particles that fall down the gap created by adjustable side doors. The angle of the beveling is also 45 degrees, with the same intention as previously stated.



(a) Version D



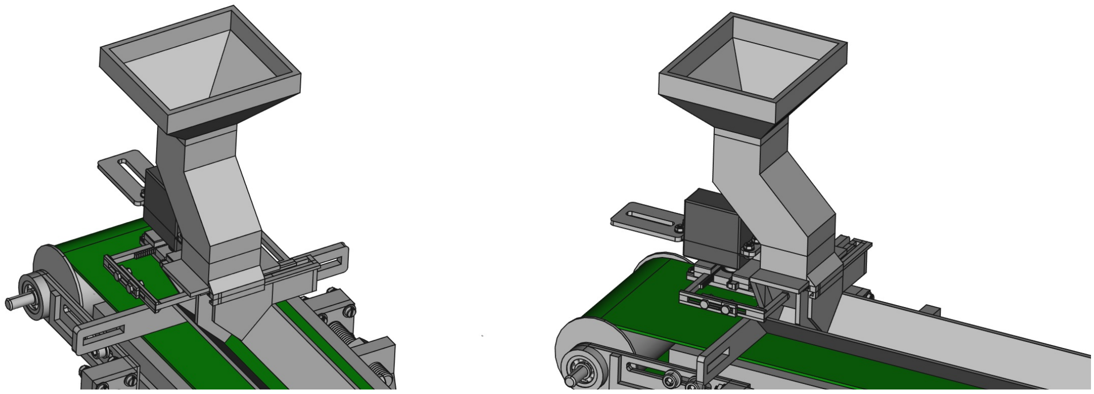
(b) Side View



(c) Top View

Fig. 67: Version D Design

The following illustration depicts the version C of the conveyor feeder on a conveyor belt.



(a) Front View (b) Side View

Fig. 68: Version D on a Conveyor Belt.

In conclusion, the feeding mechanism represents a crucial component in the operation of the sample divider, as its design directly affects the desired cross-section of the material stream, thereby influencing the accuracy of sampling.

3.2 Software implementation

In order to establish communication with the laboratory environment, the OPC UA communication protocol was employed. OPC UA was selected for its interoperability, which ensures seamless communication across devices and platforms. This is bolstered by robust security measures, including encryption and access control. Reliability is guaranteed through error detection and recovery, while scalability accommodates both small-scale setups and expansive industrial networks. As an industry standard endorsed by the OPC Foundation, OPC UA offers stability, long-term support, and rich functionality, including data modelling and event handling. Its platform independence and future-proofing capabilities make it a versatile and forward-thinking choice for industrial automation solutions.

A free OPC-UA library was selected for the use of OPC UA communication protocol due to its cost-effective access to OPC-UA functionality, eliminating licensing fees and reducing development expenses. The advantages of open-source flexibility, community support, and customisable features enable greater control over the project. This library comes with extensive documentation and examples, facilitating implementation and accelerating development. Furthermore, they facilitate collaboration and innovation within the developer community, thereby fostering continuous improvement and adaptation to evolving industrial needs.

The Free OPC-UA Library provides the requisite tools to implement both server and client applications. This enables flexibility and customisation tailored to specific project requirements. By offering a range of features for both server and client implementations, such as data modelling, event handling, and secure communication, it is possible to create robust and scalable solutions.

In this project, an OPC UA client serves as the control interface for managing the electrical components of a sample divider system. The system's core, an Arduino MEGA microcontroller supplied by JKI, acts as the central control unit, governed by the Arduino software. This microcontroller offers a multitude of input/output pins, rendering it an optimal choice for this project, which necessitates numerous connections to motors, potentiometers, LEDs, and other components. Its robust processing power enables the execution of complex tasks in an efficient manner, while its extensive popularity ensures a wealth of resources for development and troubleshooting.

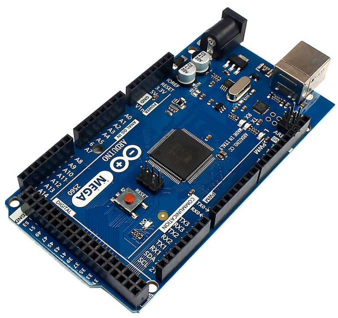


Fig. 69: Arduino Mega 2560 Board [34]

The following sections will provide detailed specifications of the OPC server, client, and Arduino software utilized in the project. Each section will offer comprehensive information on their setup, functionality, and integration within the system, thereby facilitating a clear understanding of their roles and interactions within the broader context of the project.

3.2.1 OPC UA server

In general, a single server is employed to monitor the different variables originating from various laboratory devices. This rationale underpins the decision to install the server on a Raspberry Pi board.

The Raspberry Pi is a single-chip microcomputer that includes an HDMI port for connecting a monitor, several USB ports for a keyboard, mouse and other devices. Unlike the Arduino, the Raspberry Pi uses its Raspberry Pi OS, which enables the Raspberry Pi to be used not only to control and manage various devices, but also to develop applications.

The Raspberry Pi 3 model B+ was selected for its optimal characteristics and availability. It offers a 1.4GHz 64-bit quad-core processor, dual-band wireless LAN, Bluetooth 4.2/BLE, faster Ethernet, and Power-over-Ethernet support (with separate PoE HAT). The recommended power supply (voltage/current) is 5 V/2.5 A [35].

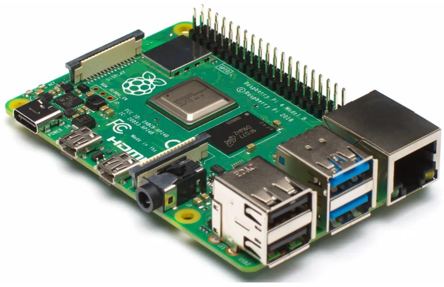


Fig. 70: Raspberry Pi 3 Model B+ [36]

In order for the Raspberry Pi to function, it is necessary to install an operating system. The Raspberry Pi OS was installed on the Raspberry Pi board using the Raspberry Pi Imager and SD card, as this operating system has been officially endorsed by Raspberry Pi [35].

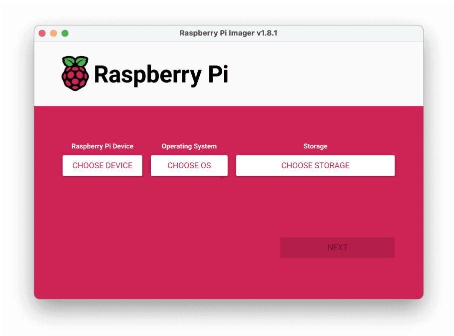


Fig. 71: Raspberry Pi Imager [35]

In the Raspberry Pi OS, an OPC UA server was developed utilising the Free OPC-UA Library. The server maintains a record of the values of variables from a specific object. These variables are under the control of the client. Whenever a change occurs in a specific variable that is under the control of the client, the server is able to detect the change and update the relevant value. The specific variables from an specific object that are stored on the server are shown in the following table.

Tab. 7: Object Variables

Object	**Variable**	**Value**
Servo S	servoS_position	0
Servo F	servoF_position	0
Servo B	servoB_position	0
Stepper	stepper_speed	0
	stepper_state	0
LED Y	ledY_state	0
LED G	ledG_state	0
LED R	ledR_state	0
Sample	sample_state	0

It is impractical and inefficient to manually start the server each time the Raspberry Pi board is powered. Therefore, a systemd service file for the server was created and set up. This service defines that the server will automatically start right after the Raspberry Pi OS is turned on, which happens right after the Raspberry Pi is powered up. Furthermore, this service defines that whenever the server crashes (goes down), the service will automatically restart the server after 10 seconds. In order for the service to function, it was necessary to enable it first. Once enabled, the service is able to control the server by issuing commands such as start, status, restart, reload and stop.

3.2.2 OPC UA client

The OPC UA client was developed using the Free OPC-UA Library as a control interface for managing the electrical components of a sample divider system. This is the reason why the client is located on the PC, where it can be easily controlled by the operator of the sample divider. The client enables the operator to control all the variables stored in the server (Table 7) from the client.

3.2.3 Arduino IDE software

The Arduino software was developed in the Arduino Integrated Development Environment (IDE) software and uploaded into the Arduino Mega board. This microcontroller, which acts as the central control unit, is governed by the Arduino software and is used for controlling the electrical components of the sample divider. These include the position and speed of the stepper motor, positions of the servo motors and states of the LEDs, which collectively lead to the control of the sampling protocol.

3.2.4 Communication between server, client and Arduino

Communication between the server (Raspberry Pi) and the client (PC) is conducted via an Ethernet cable. Ethernet connections facilitate faster and more reliable data transfer speeds than Wi-Fi. Additionally, Ethernet connections provide a more secure and stable network connection, reducing the likelihood of interference or signal loss. It is crucial to ensure that both devices are on the same network and can communicate with each other. Both the server and client are configured to use static IP addresses on the same subnet. This ensures that they can communicate directly with each other without relying on DHCP. Data transfer between an OPC UA server and client over Ethernet involves the reliable transmission of OPC UA messages encapsulated within TCP packets, providing a robust and efficient communication mechanism for industrial automation applications.

The communication between the client (PC) and the Arduino is established through serial communication established via a USB cable.

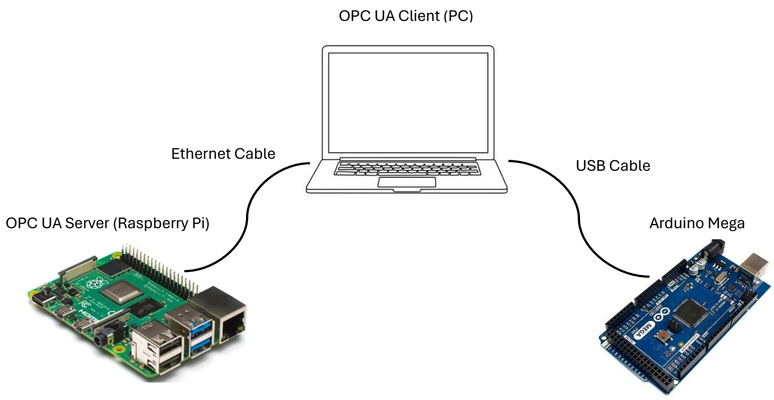


Fig. 72: Communication Scheme [37]

Data is sent from the client to the Arduino and vice versa by writing and reading strings of characters over the serial connection. The client employs threading. The read_from_serial function runs continuously in a separate thread to handle incoming data from the Arduino board connected via serial communication (USB). This function is responsible for listening for data on the serial port and processing it asynchronously. The utilisation of a distinct thread for serial communication ensures that the client application is capable of undertaking other tasks (such as sending commands to the OPC UA server) without being constrained by the arrival of serial data.

3.2.5 Graphical user interface (GUI) of the client

The FreeOpcUa Client, developed by the FreeOpcUa/python-opcua project, offers a visually intuitive environment that facilitates interaction with OPC UA servers.

This client provides a graphical interface for connecting to servers, browsing the address space, and monitoring nodes. Users can easily visualize the hierarchical structure of the server's address space, read and write node values, and manage subscriptions to data changes and events. The graphical user interface (GUI) enables the execution of complex tasks, such as method invocation and session management, thereby facilitating the efficient handling of secure communications and the performance of comprehensive OPC UA operations without the necessity of delving into the underlying code.

The first figure below illustrates the change in speed of the stepper motor in steps per second as a function of time in seconds. This speed change has been achieved by turning the potentiometer that controls the speed of the stepper motor. The second figure depicts the different values, as modified by the client, of the position of the servomotor as a function of time in seconds.

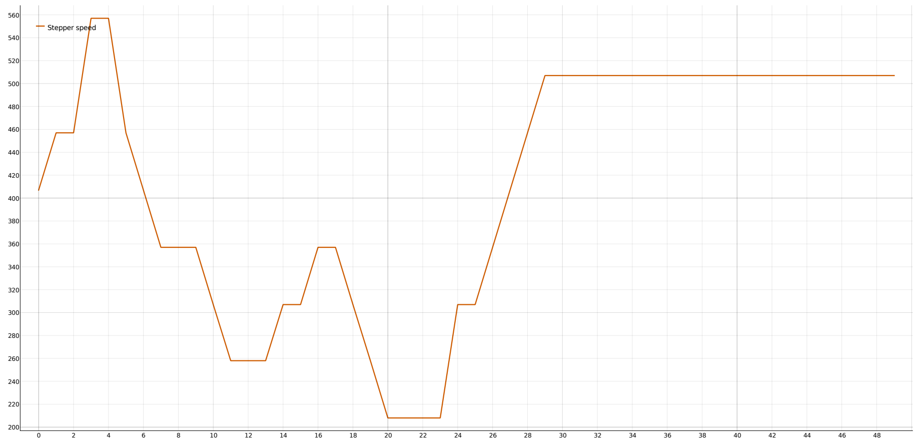


Fig. 73: Stepper Motor Speed Graph

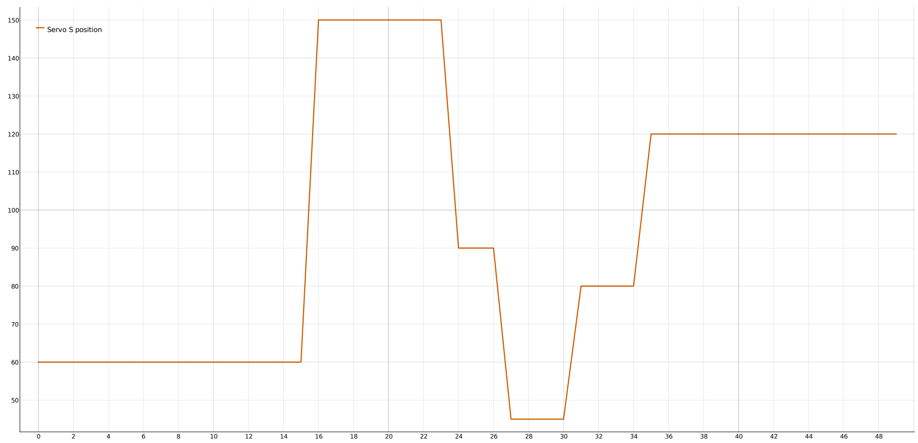


Fig. 74: Servo Motor Position Graph

The following figure illustrates the graphical user interface (GUI) of the OPC UA Client, which displays individual objects of the sample divider and their variables.

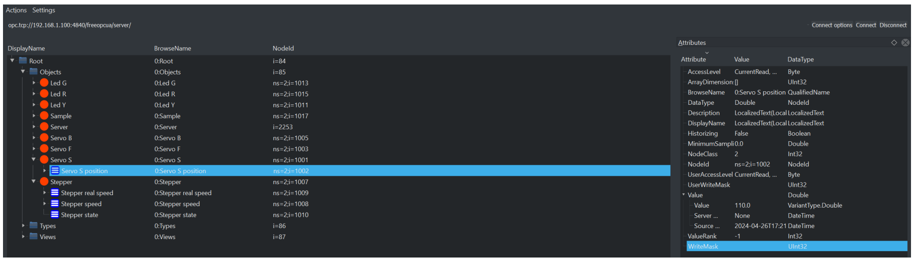


Fig. 75: OPC UA Client Graphical User Interface (GUI)

The following figure illustrates the data subscriptions for data change detection, specifically displaying the individual variables and their values.

	DisplayName	Value	Timestamp
1	Led G state	False	2024-05-19T19:14:29.082746
2	Led R state	False	2024-05-19T19:14:29.090741
3	Led Y state	True	2024-05-19T19:14:28.093749
4	Sample state	False	2024-04-26T17:21:07.908815
5	Servo B position	60.0	2024-04-26T17:21:07.888594
6	Servo F position	150.0	2024-04-26T17:21:07.880615
7	Servo S position	60	2024-05-19T19:27:09.923679
8	Stepper real speed	0.0	2024-04-26T17:21:07.893427
9	Stepper speed	65	2024-05-19T19:25:00.540712
10	Stepper state	False	2024-05-19T19:14:29.074802

Fig. 76: Data Subscriptions for Data Change Detection

In conclusion, the potentiometer, which is controlled by the Arduino software, can be used to alter the speed of the stepper motor and the position of the servo motor according to the instructions of the client. The variables on the server are updated, and by subscribing to the data change, it is possible to observe the changes in values on the GUI of the client. This illustrates the communication between the Arduino, client and server.

3.3 Sampling protocol

The objective is to produce a representative sample of a specific fraction of the input material. As the sample divider does not utilise any sensors, due to the low cost of development, we are unable to access any feedback that would assist in achieving more precise results. Consequently, the primary focus is to obtain an representative sample. This is based on producing a perfect stream of particles on the conveyor belt, one after the other. Therefore, the primary unit for the sampling will be the length.

In order to achieve a representative sample, the final sample should consist of as many increments as possible, and these increments must be chosen at random intervals. This is why the sampling is divided into windows with the same lengths. Inside each window, there is exactly one increment that is positioned randomly within this window. Since the objective is to produce a sample that corresponds to some specific fraction (sample fraction) of the input material, the length of the window corresponds to the following formula:

$$\text{Window} = \frac{\text{Increment}}{\text{Sample fraction}} \tag{1}$$

This relationship ensures that each increment constitutes a sample fraction with respect to the one window. These windows then repeat until all the material has been sampled. To ensure the random position of the increment inside the window, each increment is sampled with a random offset, calculated by the following formula:

$$\text{Offset} = \text{random}(0, \text{window} - \text{increment}) \tag{2}$$

In order to initiate the sampling process, it is essential to specify the aforementioned parameters within the software. These include the increment length and the fraction of the total input material to be included in the final sample (sample fraction). The client automatically requests these parameters from the operator of the sample divider.

The theory of sampling (TOS) stipulates that the minimal acceptable dimension of a sampling device (e.g. a sampling shovel) is calculated by the following formula:

$$\text{Minimum Increment Length} = 3 \times \text{Largest Particle Length} \tag{3}$$

In contrast to the conventional approach, the conveyor belt is employed as the sampling device. This implies that the dimensions of the sampling device (e.g. a sampling shovel) correspond to the length of the conveyor belt movement.

In order to obtain a representative sample of the greatest number of increments possible, it is necessary that the increment length correspond to the minimum increment length.

Once the parameters of the increment length and sample fraction have been defined within the client, the sample protocol proceeds in accordance with the following instructions in sequence:

1. Generate uniform random offset of sampling increment within window: offset = random(0, window - increment)
2. Move belt about the length of offset
3. Stop belt
4. Move flap to sample position
5. Move belt about the length of increment
6. Stop belt
7. Move flap to bulk position
8. Move belt about the length of the rest of the window (window - offset - increment)

Subsequently, these steps within the window are repeated until all the input material is sampled. It is of paramount importance to stop the belt for flap movement, as this greatly facilitates the avoidance of systematic sampling error.

The Arduino software is structured in an overall loop. In order to respond to client commands in a timely manner, while controlling the sampling protocol, which runs in a loop and takes longer to complete, the overall loop has been divided into two loops, one faster and one slower.

The faster loop, which operates at a high frequency, is responsible for processing commands from the client and controlling the movement of the stepper motor. This is essential because in order for a stepper motor to operate smoothly and consistently, it must receive signals in a fast and regular interval.

Conversely, the slow loop, which comprises a sampling protocol, is considerably slower than is required to handle commands from the client and control the movement of the stepper motor. Consequently, there is a necessity to accelerate the speed of the slow loop in order to fulfil these requirements. This is the rationale behind the decision to divide the sampling protocol using switch statements. The switch statement is employed to select a specific block of code to execute. It is of paramount importance that each block employs a non-blocking technique, which precludes the inclusion of any element that might impede the uninterrupted and expeditious flow of the overall loop, such as delays. This approach enables the Arduino loop to operate at a markedly accelerated pace by breaking from each block after a certain condition is met.

The blocks of the switch statement are as follows:

Block 1: This block is responsible for setting the initial parameters of the sampling protocol, including activating the stepper motor and positioning the servo motor attached to the sampling flap to the position where the material is directed to the remaining material box and positioning other servo motors to a certain position allowing for the adjustments of the conveyor feeder. Subsequently, the conditions are verified to ascertain whether they have been met.

Block 2: This block is responsible for calculating the number of steps that the stepper must take in order for the belt to supply the material to the sampling flap. This is done only for the first iteration of the sampling protocol. Subsequently, the condition is verified to ascertain whether the requisite number of steps has been completed.

Block 3: The algorithm calculates the number of steps required for the stepper to move the belt for offset length and then moves the stepper with the requisite number of steps. It then stops the stepper motor and verifies that the stepper has indeed stopped.

Block 4: The servo motor attached to the sampling flap is moved to the position where the material is to be directed for the final sample. This is then verified by the servo motor reaching its designated position.

Block 5: This block is responsible for determining whether a specific time interval has elapsed, thereby enabling the stepper motor to commence its movement.

Block 6: The stepper motor is initiated and its movement is monitored to ascertain whether it has commenced operation.

Block 7: The algorithm calculates the number of steps required for the stepper motor to move the belt for the length of one increment, then moves the stepper for the calculated steps and then stops the stepper motor. Finally, the block verifies that the stepper has stopped.

Block 8: The servo attached to the sampling flap is moved to a position where the material is directed into the remaining material box. This is followed by verification that the servo motor has reached its position.

Block 9: This block is again responsible for determining whether a specific time interval has elapsed, thereby enabling the stepper motor to commence its movement.

Block 10: The stepper motor is initiated and its movement is verified.

Block 11: The number of steps required for the stepper motor to move the belt for the length corresponding to the remaining window length (window - offset - increment) is calculated, and the stepper is then moved in accordance with this calculation.

The library used for controlling the stepper motor is the AccelStepper library. This library enables the dynamic control of the stepper motor, which is necessary to prevent the rounded particles from rolling the belt during the stopping and starting of the stepper motor. Therefore, acceleration and deceleration limitations were set for the sampling protocol. Furthermore, the library enables the output of the stepper motor's current speed in steps per second. Given the output of the stepper speed in steps per second, the angular speed in degrees can be calculated. It should be noted that each step of the stepper motor corresponds to an angle of 1.8 degrees (Table 4). This angle can then be converted to radians using the following formula:

$$\omega_{\text{stepper}} = \omega_{\text{steps}} \times 1.8 \times \frac{\pi}{180} \tag{4}$$

The linear speed of the belt between the pulleys is then calculated from the angular speed of the stepper motor in radians, according to the following formula:

$$v = \omega_{\text{stepper}} \times r_{\text{small}} \tag{5}$$

The angular speed of the shaft where the larger pulley is rotating can be calculated as follows:

$$\omega_{\text{shaft}} = v \times r_{\text{big}} \tag{6}$$

The linear speed of the conveyor belt is calculated using following formula:

$$v_{\text{belt}} = \omega_{\text{shaft}} \times R_{\text{belt}} \tag{7}$$

Finally, the total number of steps required for the stepper motor to move the belt for a given length (beltMovement) is calculated according to the following formula.

$$\text{steps} = \left(\frac{\text{beltMovement}}{v_{\text{belt}}}\right) \times \omega_{\text{steps}} \tag{8}$$

In order to make more precise calculations of the theoretically calculated belt movement inside the Arduino software and the real belt movement, a test must be taken to compare them. The test compared the time passed between a specific length of the belt. This specific length was taken as the measured length of the belt. The test was taken under a specific constant speed of the stepper motor, 400 steps per second.

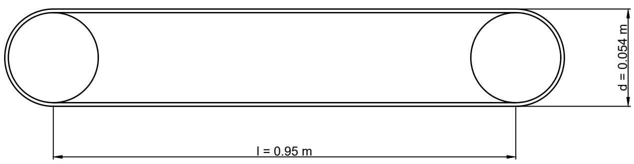


Fig. 77: Measured Dimensions of the Belt

$$\text{BeltLength} = \pi d + 2l = \pi \cdot 0.054 + 2 \cdot 0.95 \approx 2.07 \text{ m} \tag{9}$$

In order to obtain more precise measurements of the real time, a number of measurements were taken using a stopwatch.

Tab. 8: Time Measurements in Seconds

Lap	1	2	3	4	5	6	7	8	9	10
Time [s]	11.51	11.46	11.40	11.49	11.58	11.63	11.43	11.51	11.44	11.47

The mean value of the time can be calculated using the formula:

$$\text{Mean time} = \frac{1}{N}\sum_{i=1}^{N} t_i \tag{10}$$

where t_i is the i-th measurement of time and N is the total number of measurements.

Given the time measurements the mean value of the time is:

$$\text{Mean time} = \frac{11.51 + 11.46 + 11.40 + 11.49 + 11.58 + 11.63 + 11.43 + 11.51 + 11.44 + 11.47}{10} = 11.49 \text{ s}$$

The values obtained from the real-time measurement and the calculated time differ, indicating the necessity to incorporate the correction coefficient (CF) into the calculated time. The CF can be calculated as follows:

$$\text{CF} = \frac{\text{Mean time}}{\text{Calculated time}} = \frac{11.49}{9.17} = 1.253 \tag{11}$$

The incorporation of the correction coefficient into the calculation of the total number of steps that the stepper motor must take in order to move the belt with greater precision.

$$\text{steps} = \left(\frac{\text{beltMovement}}{v_{\text{belt}}}\right) \times \omega_{\text{steps}} \times \text{CF} \tag{12}$$

3.4 Electrical System Integration

The OPC UA server, which is located on the Raspberry Pi board, is intended for use in a laboratory setting where it can be easily connected to the electrical network. In order to ensure optimal performance, it is powered by an AC/DC adapter that provides 5 V and 2.5 A, which is compatible with the Raspberry Pi's power requirements.

The communication between the OPC UA client, which is located on a PC, and the Arduino Mega board is established via an USB cable. Consequently, it is also possible to power the board with the same USB cable. The Arduino board outputs a voltage of 5 V, which is sufficient to power electrical components such as LEDs, potentiometer and lever switch.

In consideration of the prospective utilisation of the sample divider for the field division of samples and the proposal that a 12 V car battery supply would be sufficient, the system's electrical system was designed to meet this requirement.

The stepper motor is controlled and powered by the DRV8825 motor driver, which can accept an input voltage between 8.2 and 45 V. This allows for direct supply by a 12 V power supply. The sample divider comprises three identical MG996R servo motors, which require a supply voltage of 4.8 to 7.2 V. These motors could be potentially powered by an Arduino, which outputs 5 V. However, these servos require a high current supply, which is why an external power supply is necessary. As the required voltage is below 12 V, the step-down voltage regulator S13V30F5, supplied by JKI, was employed to reduce the voltage from 12 to 5 V, which is suitable for the aforementioned servo motors. For the testing of the sample divider, reasons of price and availability led to the use of an available programmable power supply, the Rigol DP832A, with a 12 V output.

Each electrical component is connected in parallel to maintain the desired voltage supply. It is also important to maintain the common ground of the electrical circuit of electrical components to ensure the proper functionality. The capacitors were used for the stepper motor and servo motors to ensure a constant voltage supply. The capacitors were also used for the potentiometer since the Arduino reads its output, so it is important that the voltage inside the potentiometer does not fluctuate.

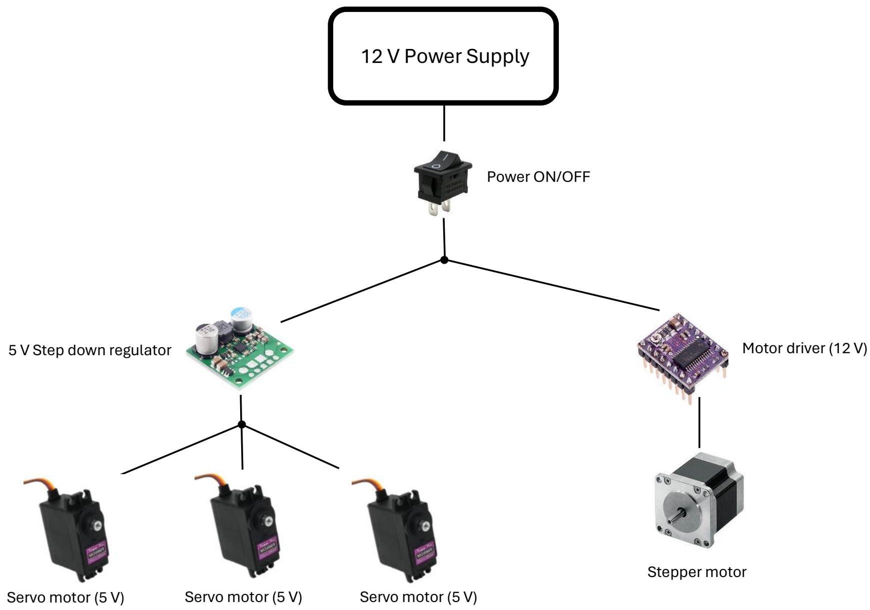
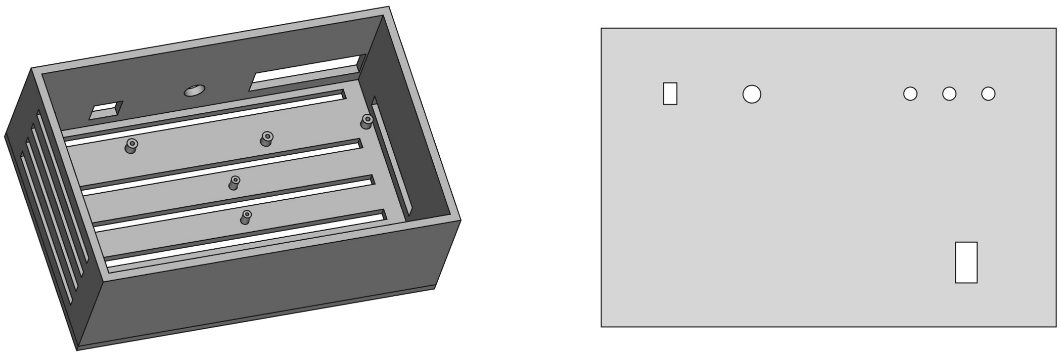


Fig. 78: Simplified Schematic of 12 V Circuit [38]

A control panel was developed with the objective of closing the electronic components. The interior of the control panel was designed to accommodate boards of the Arduino Mega, Raspberry Pi, and voltage regulator. The front panel was designed to fit the components of the main power switch, potentiometer for controlling the speed of the stepper motor, and three LEDs. The yellow LED indicates that the sample divider is ready for sampling, the green LED indicates that the sampling is in progress, and the red LED indicates any error or problem with the sample divider.

The front panel was also designed to accommodate a lever switch for enabling and disabling sampling. While it is theoretically possible to calculate the time of the sampling from the input material and from the assumption of a particle stream one after the other on the conveyor belt, this is challenging to achieve in practice. In practice, the sampling time will typically be shorter than the theoretical sampling time. This is why it is necessary to disable or stop the sampling process once all the material has been sampled.

Overall, the control panel has ventilation gaps to control the heat inside the panel.



(a) Rear Part

(b) Front Part

Fig. 79: Control panel

3.5 Evaluation

This section will provide an overview of the different types of design solutions for conveyor feeders and the various materials used for evaluating sample dividers. The objective is to compare how different designs of conveyor feeders and different material types influence the accuracy of the sampling procedure.

3.5.1 Material used for evaluation

The sample divider is designed to be adjustable to different materials, which is why the material for evaluation is of varying size and shape. The specific material used is seed-type material. As the testing of the sampling is very time-consuming, the specific available seeds (some of them supplied by JKI) for testing will only be coffee beans, pumpkin seeds, large beans and Tic Tac dragees.

(a) Coffee Beans [39] (b) Pumpkin Seeds [40] (c) Large Beans [41] (d) Tic Tac Dragees [42]

Fig. 80: Evaluation Material

In order to ascertain the accuracy of the sampling procedure and the precision of the sample divider, it is necessary to test a representative sample of particles of a uniform size, shape and weight distribution. This is because the accuracy of the sample divider is contingent upon these factors. Failure to meet this requirement will result in a systematic error. Consequently, the accuracy of the sample divider will be evaluated using 140 Tic Tac dragees, as each dragee has a similar weight, size and shape.

The testing of other materials, including coffee beans, pumpkin seeds and large beans, will be conducted using a weight-based approach rather than a number-based approach. This is because weighing the material is a more straightforward and effective method than counting each particle, despite the potential for less precise results. This is due to the fact that the specific seeds are combined of different particle sizes, which cases systematic error.

3.5.2 Conveyor feeders used for evaluation

In total 4 versions of conveyor feeders will be used for evaluation.

Evaluation of Conveyor Feeder Version A

The primary objective of this testing is to ascertain the impact of the material stream generation within the feeding mechanism on the accuracy of the sampling process.

The initial objective is to assess the behaviour of different materials bonded to the front door of this version, with a particular focus on rubber and foil, in order to ascertain the impact of these materials on the sampling process.

This version of the conveyor feeder will be subjected to testing on a range of sampling parameters and values, with a specific focus on the influence of input material quantity (100 and 200 grams) on sampling accuracy. Additionally, the impact of portioning the input material at 1/3 and 1/2 for the final sample will be examined. Finally, the values of increment length, in particular the minimum increment length and the length of five times the minimum increment length, will be evaluated.

In order to assess the aforementioned parameters, a sample divider will be subjected to testing on the same sampling material, specifically coffee beans.

In order to assess the accuracy and behaviour of the sampling protocol, the number of steps of the stepper motor required to move the belt to the required length is displayed. This includes the lengths of the total Window, Offset, Increment and the Rest of the window (window - offset - increment), which are calculated within the software.

Furthermore, this version will be subjected to testing on a range of materials, including pumpkin seeds, large beans and Tic Tac dragees.

In order to ascertain the efficacy of the sample divider on materials of varying particle size and shape, it is necessary to make initial adjustments to the conveyor feeder.

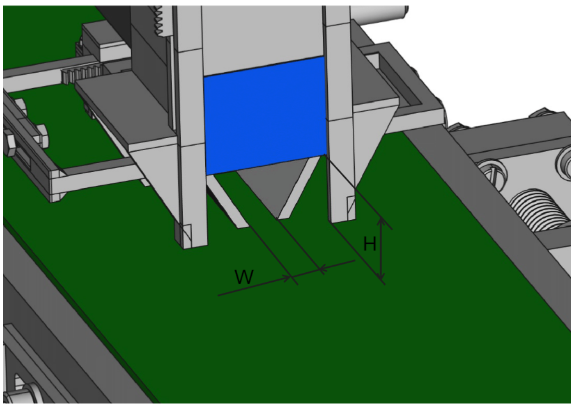


Fig. 81: Initial Configuration of the Version A and B

The specific configuration of the conveyor feeder was designed to establish a continuous stream of material with the smallest cross-section possible on the conveyor belt. The specific values of parameters of width and height used for versions A and B for the specific material type are presented in the following table.

Tab. 9: Configuration Parameters for Versions A and B

Material Type	**Width - W [mm]**	**Height - H [mm]**
Coffee beans	12	15
Pumpkin seeds	20	15
Large beans	30	25
Tic tac	12	12

It is of the utmost importance to configure the conveyor feeder in such a way as to achieve the smallest possible cross-section of the material stream. This is because it facilitates the production of a greater number of increments, thereby ensuring a more representative sample.

Evaluation of Conveyor Feeder Version B

The primary objective of testing this version is to ascertain the impact of the weight of the material inside the feeding mechanism on the accuracy of the sampling procedure. This version should be tested to determine whether there is a difference in the results obtained when compared to version A.

The testing will be conducted on a material comprising coffee beans, pumpkin seeds and Tic Tac dragees.

Evaluation of Conveyor Feeder Version C

The primary objective of this experimental procedure is to ascertain the impact of creating the material stream outside the feeding mechanism.

The test material for this particular version is composed of coffee beans, pumpkin seeds, and Tic Tac dragees.

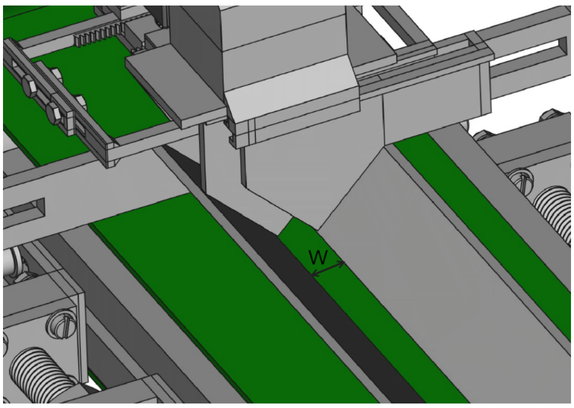


Fig. 82: Initial Configuration of the Version C and D

The specific values of the conveyor feeder configuration employed for versions C and D for the specific material type are presented in the following table.

Tab. 10: Configuration Parameters for Versions C and D

Material Type	**Width - W [mm]**
Coffee beans	24
Pumpkin seeds	25
Tic tac	25

Evaluation of Conveyor Feeder Version D

The primary objective of the testing of the version is to ascertain whether the weight of the material slope inside the feeding mechanism affects the accuracy of the sampling. This will enable a comparison to be made between this version and the conveyor feeder version C.

The material to be tested for this version is comprised of coffee beans, pumpkin seeds and Tic Tac dragees.

3.5.3 Methods for evaluation

The results of the tests will be evaluated according to the following parameters: the sum of the sample and bulk weight, the mean value, the standard deviation and the systematic error.

The sum of the sample and bulk weights will be calculated using the following equation:

$$\text{Sum of Sample and Bulk Weight} = \text{Sample Weight} + \text{Bulk Weight} \quad [\text{g}] \qquad (13)$$

- Sum of Sample and Bulk Weight: Total weight in grams, which is the sum of the sample weight and the bulk weight.
- Sample Weight: Sample weight, which represents the weight of the sampled material in the sample box.
- Bulk Weight: Bulk weight, which is the weight of the sampled material in the remaining material box.

Given the time-consuming nature of the sampling test, the total number of tests for each parameter under investigation will be five. The mean value will be calculated using the following equation:

$$\text{Mean Value} = \frac{\sum_{i=1}^{N} W_i}{N} \quad [\text{g}] \qquad (14)$$

- Mean Value: Mean value of the sample weights.

- W_i: Weight of the i-th sample, where $i = 1, 2, \ldots, N$.
- N: Number of samples.

In order to ascertain the extent to which each value differs from the mean value, the standard deviation will be calculated using the following formula:

$$\text{Standard Deviation} = \sqrt{\frac{\sum_{i=1}^{N}(W_i - \text{Mean Value})^2}{N}} \quad [\text{g}] \tag{15}$$

- σ: Standard deviation of the sample weights.
- W_i: Weight of the i-th sample, where $i = 1, 2, \ldots, N$.
- Mean Value: Mean value of the sample weights.
- N: Number of samples.

The systematic error will be calculated using the following formula:

$$\text{Systematic Error} = \text{Reference Value} - \text{Mean Value} \quad [\text{g}] \tag{16}$$

- Systematic Error: The systematic error of the sample weights.
- Reference Value: The reference value against which the mean value is compared.
- Mean Value: The mean value of the sample weights.

The reference value is contingent upon the weight of the input material and the fraction of the sample weight. It is calculated using the following formula:

$$\text{Reference Value} = \text{Input Weight} \times \text{Sample Fraction} \quad [\text{g}] \tag{17}$$

- Reference Value: The reference value in grams (g).
- Input Weight: The input weight of the material to be sampled.
- Sample Fraction: The fraction of input material to be sampled.

The following table presents the specific values of the reference values.

Tab. 11: Reference Values based on Input Weight and Sample Fraction

Input Weight	**Sample Fraction**	**Reference Value**
100	$\frac{1}{3}$	33.333
200	$\frac{1}{3}$	66.667
100	$\frac{1}{2}$	50
200	$\frac{1}{2}$	100

In conclusion, the previously employed methods for evaluation were based on the weight. However, for the evaluation of Tic Tac dragees, which are based on the number of particles, the evaluation is the same, but instead of evaluating the weight, the unit for evaluation is the number of particles. Furthermore, the reference value of the input of 140 Tic Tac particles and the sample fraction of 1/3 is equal to 46.662.

4 RESULTS

This chapter presents the results of testing different versions of conveyor feeders for sampling purposes.

4.1 Results of conveyor feeder version A

The following tables present the test results for coffee beans. The tests were conducted under the minimum increment length and for different weights of 100 and 200 grams.

Tab. 12: Initial Test Parameters

Material Type	Average Particle Length [m]	Minimum Increment Length [m]	Sample Fraction	Input Weight [g]
Coffee Beans	0.009	0.027	1/3	100

Tab. 13: Test Results

Test	1	2	3	4	5
Sample Weight [g]	39	42	41	39	40
Bulk Weight [g]	61	58	59	61	60
Sum of Sample and Bulk Weight [g]	100	100	100	100	100

Tab. 14: Evaluation of Sample Weight Tests

Parameter	**Value**
Mean Value	40.2 g
Standard Deviation	1.166 g
Systematic Error	6.867 g

Tab. 15: Initial Test Parameters

Material Type	Average Particle Length [m]	Minimum Increment Length [m]	Sample Fraction	Input Weight [g]
Coffee Beans	0.009	0.027	1/3	200

Tab. 16: Test Results

Test	1	2	3	4	5
Sample Weight [g]	80	75	73	79	77
Bulk Weight [g]	120	125	127	121	123
Sum of Sample and Bulk Weight [g]	200	200	200	200	200

Tab. 17: Evaluation of Sample Weight Tests

Parameter	**Value**
Mean Value	76.8 g
Standard Deviation	2.561 g
Systematic Error	10.134 g

The following table presents the calculated steps required for a stepper motor to move the belt for the lengths of Window, Offset, Increment and Rest (Window - Offset - Increment). It also shows different lengths of Offset values, which are randomly generated inside each window.

Tab. 18: Calculated Steps

Loop	1	2	3	4	5
Window [steps]	181	181	181	181	181
Offset [m]	0.02	0.03	0.05	0.01	0.04
Offset [steps]	44	66	111	22	88
Increment [steps]	59	59	59	59	59
Rest [steps]	121	121	10	99	10

The following tables present the results of different increment length, specifically the five times the minimum increment length. They also present the results for different weights of 100 and 200 grams.

Tab. 19: Initial Test Parameters

Material Type	Average Particle Length [m]	5 × Minimum Increment Length [m]	Sample Fraction	Input Weight [g]
Coffee Beans	0.009	0.135	1/3	100

Tab. 20: Test Results

Test	1	2	3	4	5
Sample Weight [g]	29	33	37	31	34
Bulk Weight [g]	71	67	63	69	66
Sum of Sample and Bulk Weight [g]	100	100	100	100	100

Tab. 21: Evaluation of Sample Weight Tests

Parameter	**Value**
Mean Value	32.8 g
Standard Deviation	2.713 g
Systematic Error	0.533 g

Tab. 22: Initial Test Parameters

Material Type	Average Particle Length [m]	5 × Minimum Increment Length [m]	Sample Fraction	Input Weight [g]
Coffee Beans	0.009	0.135	1/3	200

Tab. 23: Test Results

Test	1	2	3	4	5
Sample Weight [g]	58	65	61	60	66
Bulk Weight [g]	142	135	139	140	134
Sum of Sample and Bulk Weight [g]	200	200	200	200	200

Tab. 24: Evaluation of Sample Weight Tests

Parameter	**Value**
Mean Value	62 g
Standard Deviation	3.033 g
Systematic Error	4.666 g

The following table presents the calculated steps required for the stepper motor to move the belt for specific lengths, with the increment length equal to five times the minimum increment length.

Tab. 25: Calculated Steps

	1	2	3	4	5
Window [steps]	908	908	908	908	908
Offset [m]	0.05	0.08	0.19	0.06	0.21
Offset [steps]	111	177	421	133	466
Increment [steps]	299	299	299	299	299
Rest [steps]	541	408	408	453	364

The following tables present the results of tests conducted on samples of varying proportions of the total input material, specifically 1/2, once more for different weights of 100 and 200 grams.

Tab. 26: Initial Test Parameters

Material Type	Average Particle Length [m]	5 × Minimum Increment Length [m]	Sample Fraction	Input Weight [g]
Coffee Beans	0.009	0.135	1/2	100

Tab. 27: Test Results

Test	1	2	3	4	5
Sample Weight [g]	43	45	42	47	44
Bulk Weight [g]	57	55	58	53	56
Sum of Sample and Bulk Weight [g]	100	100	100	100	100

Tab. 28: Evaluation of Sample Weight Tests

Parameter	**Value**
Mean Value	44.2 g
Standard Deviation	1.720 g
Systematic Error	5.8 g

Tab. 29: Initial Test Parameters

Material Type	Average Particle Length [m]	5 × Minimum Increment Length [m]	Sample Fraction	Input Weight [g]
Coffee Beans	0.009	0.135	1/2	200

Tab. 30: Test Results

Test	1	2	3	4	5
Sample [g]	80	91	82	88	92
Bulk [g]	120	109	118	112	108
Sum of Sample and Bulk Weight [g]	200	200	200	200	200

Tab. 31: Test evaluation of the number of sample particles.

Parameter	**Value**
Mean Value	86.6 g
Standard Deviation	4.8 g
Systematic Error	13.4 g

The following table presents the calculated steps required for the stepper motor to move the belt for a specific length. The steps were calculated using a different fraction of the final sample from the input material, specifically 1/2.

Tab. 32: Calculated Steps

	1	2	3	4	5
Window [steps]	599	599	599	599	599
Offset [m]	0.02	0.03	0.07	0.05	0.11
Offset [steps]	37	71	157	108	253
Increment [steps]	299	299	299	299	299
Rest [steps]	62	86	48	184	128

The following table presents the results of tests conducted on the material type of pumpkin seeds.

Tab. 33: Initial Test Parameters

Material Type	Average Particle Length [m]	5 $\times$ Minimum Increment Length [m]	Sample Fraction	Input Weight [g]
Pumpkin seeds	0.015	0.225	1/3	100

Tab. 34: Test Results

Test	1	2	3	4	5
Sample Weight [g]	27	25	22	36	32
Bulk Weight [g]	73	75	78	64	68
Sum of Sample and Bulk Weight [g]	100	100	100	100	100

Tab. 35: Evaluation of Sample Weight Tests

Parameter	**Value**
Mean Value	28.4 g
Standard Deviation	5.004 g
Systematic Error	4.933 g

The following table presents the results of tests conducted on the material type of large beans.

Tab. 36: Initial Test Parameters

Material Type	Average Particle Length [m]	5 × Minimum Increment Length [m]	Sample Fraction	Input Weight [g]
Large beans	0.03	0.45	1/3	100

Tab. 37: Test Results

Test	1	2	3	4	5
Sample Weight [g]	21	19	35	22	28
Bulk Weight [g]	79	81	65	78	72
Sum of Sample and Bulk Weight [g]	100	100	100	100	100

Tab. 38: Evaluation of Sample Weight Tests

Parameter	**Value**
Mean Value	25 g
Standard Deviation	5.831 g
Systematic Error	8.333 g

The following table presents the results of tests conducted on the material type of Tic Tac dragee with a specific number of particles of 140.

Tab. 39: Initial Test Parameters

Material Type	Particle Length [m]	5 × Minimum Increment Length [m]	Sample Fraction	Number of Particles
Tik tac	0.01	0.15	1/3	140

Tab. 40: Test Results

Test	1	2	3	4	5
Number of Sample Particles	44	41	41	40	45
Number of Bulk Particles	96	99	99	100	95
Sum of Sample and Bulk Particles	140	140	140	140	140

Tab. 41: Evaluation of the Number of Sample Particles Tests

Parameter	**Value**
Mean Value	42.2 g
Standard Deviation	1.939 g
Systematic Error	4.462 g

4.2 Results of conveyor feeder version B

This section presents the results of tests conducted on the conveyor feeder version B.

The following table presents the results of tests conducted on the material type of coffee beans.

Tab. 42: Initial Test Parameters

Material Type	Average Particle Length [m]	5 × Minimum Increment Length [m]	Sample Fraction	Input Weight [g]
Coffee Beans	0.009	0.135	1/3	100

Tab. 43: Test Results

Test	1	2	3	4	5
Sample Weight [g]	35	29	30	34	33
Bulk Weight [g]	65	71	70	66	67
Sum of Sample and Bulk Weight [g]	100	100	100	100	100

Tab. 44: Evaluation of Sample Weight Tests

Parameter	**Value**
Mean Value	32.8 g
Standard Deviation	2.315 g
Systematic Error	0.533 g

The following table presents the results of tests conducted on the material type of pumpkin seeds.

Tab. 45: Initial Test Parameters

Material Type	Average Particle Length [m]	5 × Minimum Increment Length [m]	Sample Fraction	Input Weight [g]
Pumpkin seeds	0.015	0.225	1/3	100

Tab. 46: Test Results

Test	1	2	3	4	5
Sample Weight [g]	26	32	29	35	27
Bulk Weight [g]	74	68	71	65	73
Sum of Sample and Bulk Weight [g]	100	100	100	100	100

Tab. 47: Evaluation of Sample Weight Tests

Parameter	**Value**
Mean Value	29.8 g
Standard Deviation	3.311 g
Systematic Error	3.533 g

The following table presents the results of tests conducted on the material type of Tic Tac dragee with a specific number of particles of 140.

Tab. 48: Initial Test Parameters

Material Type	Particle Length [m]	5 × Minimum Increment Length [m]	Sample Fraction	Number of Particles
Tik tac	0.01	0.15	1/3	140

Tab. 49: Test Results

Test	1	2	3	4	5
Number of Sample Particles	43	42	46	43	45
Number of Bulk Particles	97	98	94	97	95
Sum of Sample and Bulk Particles	140	140	140	140	140

Tab. 50: Evaluation of the Number of Sample Particles Tests.

Parameter	**Value**
Mean Value	43.8 g
Standard Deviation	1.470 g
Systematic Error	2.862 g

4.3 Results of conveyor feeder version C

This section presents the results of tests conducted on the conveyor feeder version C.

The following table presents the results of tests conducted on the material type of coffee beans.

Tab. 51: Initial Test Parameters

Material Type	Average Particle Length [m]	5 × Minimum Increment Length [m]	Sample Fraction	Input Weight [g]
Coffee Beans	0.009	0.135	1/3	100

Tab. 52: Test Results

Test	1	2	3	4	5
Sample Weight [g]	34	32	33	36	31
Bulk Weight [g]	66	68	67	64	69
Sum of Sample and Bulk Weight [g]	100	100	100	100	100

Tab. 53: Evaluation of Sample Weight Tests

Parameter	**Value**
Mean Value	33.2 g
Standard Deviation	1.720 g
Systematic Error	0.133 g

The following table presents the results of tests conducted on the material type of pumpkin seeds.

Tab. 54: Initial Test Parameters

Material Type	Average Particle Length [m]	5 × Minimum Increment Length [m]	Sample Fraction	Input Weight [g]
Pumpkin seeds	0.015	0.225	1/3	100

Tab. 55: Test Results

Test	1	2	3	4	5
Sample Weight [g]	31	32	35	31	30
Bulk Weight [g]	69	68	65	69	70
Sum of Sample and Bulk Weight [g]	100	100	100	100	100

Tab. 56: Evaluation of Sample Weight Tests

Parameter	**Value**
Mean Value	31.8 g
Standard Deviation	1.720 g
Systematic Error	1.533 g

The following table presents the results of tests conducted on the material type of Tic Tac dragee with a specific number of particles of 140.

Tab. 57: Initial Test Parameters

Material Type	Particle Length [m]	5 × Minimum Increment Length [m]	Sample Fraction	Number of Particles
Tik tac	0.01	0.15	1/3	140

Tab. 58: Test Results

Test	1	2	3	4	5
Number of Sample Particles	38	44	42	39	44
Number of Bulk particles	102	96	98	101	96
Sum of Sample and Bulk Particles	140	140	140	140	140

Tab. 59: Evaluation of the Number of Sample Particles Tests.

Parameter	**Value**
Mean Value	41.4 g
Standard Deviation	2.498 g
Systematic Error	5.262 g

4.4 Results of conveyor feeder version D

This section presents the results of tests conducted on the conveyor feeder version D.

The following table presents the results of tests conducted on the material type of coffee beans.

Tab. 60: Initial Test Parameters

Material Type	Average Particle Length [m]	5 × Minimum Increment Length [m]	Sample Fraction	Input Weight [g]
Coffee Beans	0.009	0.135	1/3	100

Tab. 61: Test Results

Test	1	2	3	4	5
Sample Weight [g]	33	29	35	31	30
Bulk Weight [g]	67	71	65	69	70
Sum of Sample and Bulk Weight [g]	100	100	100	100	100

Tab. 62: Evaluation of Sample Weight Tests

Parameter	**Value**
Mean Value	31.6 g
Standard Deviation	2.154 g
Systematic Error	1.733 g

The following table presents the results of tests conducted on the material type of pumpkin seeds.

Tab. 63: Initial Test Parameters

Material Type	Average Particle Length [m]	5 × Minimum Increment Length [m]	Sample Fraction	Input Weight [g]
Pumpkin seeds	0.015	0.225	1/3	100

Tab. 64: Test Results

Test	1	2	3	4	5
Sample Weight [g]	34	35	29	34	31
Bulk Weight [g]	66	65	71	66	69
Sum of Sample and Bulk Weight [g]	100	100	100	100	100

Tab. 65: Evaluation of Sample Weight Tests

Parameter	**Value**
Mean Value	32.6 g
Standard Deviation	2.245 g
Systematic Error	0.733 g

The following table presents the results of tests conducted on the material type of Tic Tac dragee with a specific number of particles of 140.

Tab. 66: Initial Test Parameters

Material Type	Particle Length [m]	5 × Minimum Increment Length [m]	Sample Fraction	Number of Particles
Tik tac	0.01	0.15	1/3	140

Tab. 67: Test Results

Test	1	2	3	4	5
Number of Sample Particles	39	40	44	41	45
Number of Bulk Particles	101	100	96	99	95
Sum of Sample and Bulk Particles	140	140	140	140	140

Tab. 68: Evaluation of the Number of Sample Particles Tests.

Parameter	Value
Mean Value	41.8 g
Standard Deviation	2.315 g
Systematic Error	4.862 g

4.5 Comparison of different conveyor feeder versions

This section presents a comparison of the various versions of conveyor feeders. For the purpose of comparison, the identical test parameters for each version are displayed in the subsequent table.

Tab. 69: Identical Test Parameters

5 × Minimum Increment Length [m]	Sample Fraction	Input Weight [g]	Number of Tic Tac Dragees
0.15	1/3	100	140

The following tables present the comparative data for coffee beans, pumpkin seeds and Tic Tac dragees.

Tab. 70: Comparison for Coffee Beans

Version	Standard Deviation	Systematic Error
A	2.713	0.533
B	2.315	0.533
C	1.720	0.133
D	2.154	1.733

Tab. 71: Comparison for Pumkin Seeds

Version	Standard Deviation	Systematic Error
A	5.004	4.933
B	3.311	3.533
C	1.720	1.533
D	2.245	0.733

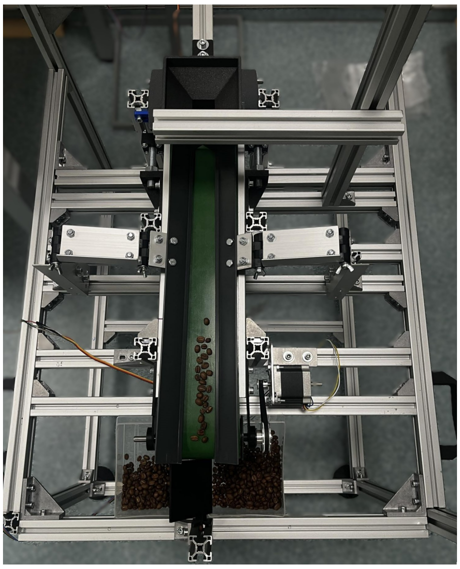
Tab. 72: Comparison for Tic Tac Dragees

Version	Standard Deviation	Systematic Error
A	1.939	4.462
B	1.470	2.862
C	2.498	5.262
D	2.315	4.862

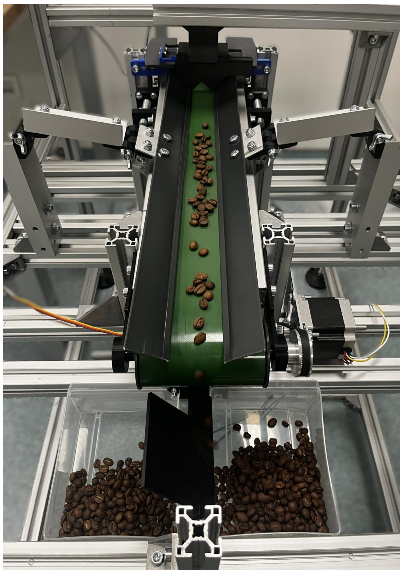
5 DISCUSSION

This chapter presents the results of four different conveyor feeding mechanisms, together with an evaluation and final comparison.

The following images demonstrate the sample divider during the sampling process of coffee beans.



(a) Top View



(b) Front View

Fig. 83: Sample Divider During Sampling

5.1 Discussion of the results of the conveyor feeder version A

Firstly, the front door of the feeding mechanism, bonded with a rubber material, exhibited greater bendability, resulting in a more continuous stream of particles exiting the feeding mechanism.

The output of the software indicates that the offset value is random and that it is changing in each window (loop of the sampling algorithm). This demonstrates that each increment is positioned randomly inside each window, which is a positive indicator in obtaining a representative sample.

The calculated steps of the stepper motor required to move the belt with a specific length demonstrated that the calculated steps for the window and increment lengths provided consistent values across all tests conducted under identical initial parameters, including the increment length and sample fraction. However, the calculated steps for the lengths of the offset and the rest of the window (window - offset - increment) change in every loop as the value of the offset length changes.

The results of the sampling tests indicated that a smaller quantity of material, specifically 100 grams, yielded more favourable outcomes in terms of both different increment lengths and sample fractions, in comparison to the 200-gram sample. This was evidenced by a smaller standard deviation and systematic error (Tables 14 and 21 and 28).

The results of the tests for 100 grams of material also demonstrated that an increment length of five times the minimum increment length resulted in a smaller systematic error, although the standard deviation was higher (Table 21) than that observed in tests conducted under the minimum increment length (Table 14).

For the 100 grams of material, the sample fraction of 1/3 resulted in a smaller systematic error, but a higher standard deviation (Table 21) than the sample fraction of 1/2 (Table 28).

This version of conveyor feeder yielded the most accurate test results for particles of the smallest size, as the systematic error was the smallest for the smallest particle tested, specifically coffee beans (Table 21). Conversely, the least accurate results provided the largest of the particles tested, specifically the large beans (Table 38).

5.2 Discussion of the results of the conveyor feeder version B

This version demonstrated the highest degree of accuracy for the particles of the smallest size tested, specifically coffee beans, with the smallest systematic error (Table 44). Conversely, it exhibited the least accuracy for the particles of the largest size tested, specifically pumpkin seeds (Table 47).

In contrast to the version A, this version demonstrated superior test results for all types of materials tested, with a smaller systematic error and standard deviation (Tables 70, 71 and 72). This indicates that the weight of the material slope might influence the accuracy of the sampling.

5.3 Discussion of the results of the conveyor feeder version C

The results of this version were found to be the most accurate for the smallest particle tested, specifically coffee beans (Table 53). Conversely, the least accurate results were observed for the Tic Tac dragees, which were the second largest particle tested (Table 59).

5.4 Discussion of the results of the conveyor feeder version D

The results indicated that this version was the most accurate for the material type of pumpkin seeds, with the least systematic error (Table 65). Conversely, the Tic Tac dragees exhibited the least accurate results, with the greatest systematic error (Table 68).

In contrast to the version C, this version exhibited smaller systematic errors for the pumpkin seeds and Tic Tac dragees (Tables 71 and 72) and higher systematic error for the coffee beans (Table 70). The standard deviations were mostly higher in contrast to the version C. This suggests that the weight of the slope had a minimal impact on the accuracy of the sampling.

5.5 Discussion of the results for all the versions of the conveyor feeder

In the case of smaller particles, such as coffee beans, achieving a continuous stream of particles one after the other was challenging. Conversely, for larger particles, such as large beans, this was more feasible.

The results of the tests demonstrated that particles were not destroyed during the sampling process and that the sum of the sample and bulk weights equalled the input material weight for all versions of conveyor feeders. This indicates that no particles were lost or trapped during the sampling process. This implies that the conveyor feeders provide sufficient design for the tested material, thus preventing loss or entrapment of material particles.

The most accurate results for the coffee beans and pumpkin seeds were obtained using version C, as the systematic error was the smallest (Tables 70 and 71). Conversely, the most accurate results for the Tic Tac dragees were obtained using version B (Table 72).

In conclusion, although the results of some specific sample fractions for some cases were not particularly precise, this does not affect the overall correctness of the sampling, as the objective is to obtain a representative sample. Overall, the most favourable outcomes were observed in the tests conducted with version C of the material type, coffee beans. This was attributed to the smallest systematic error (Table 70).

6 CONCLUSION

The principal objective of this thesis was to develop an inexpensive automatic sample divider that is adjustable to seeds with different shapes and sizes and provides small representative increments of material that make up the final representative sample, which forms a certain fraction of the input material to be sampled.

The individual components of the sample divider were developed and designed using FreeCAD software, a free computer-aided design (CAD) software that enables the publication of these components in the Journal of Open Hardware.

The sample divider was developed based on a mini conveyor belt with the sampling flap situated at the end of the conveyor belt, allowing for the input material to be sampled into the sample and remaining material box. To facilitate the feeding of material onto the conveyor belt, a conveyor feeder was developed, capable of sampling material of total volume up to 2 litres. The conveyor feeder comprises the hopper and feeding mechanism. This enables the feeder to accommodate a greater volume of input material when required, as the hopper can be easily attached or detached from the feeding mechanism. Four different versions of conveyor feeders were developed and subjected to testing.

A series of tests were conducted on each version of conveyor feeders with a range of materials, including coffee beans, pumpkin seeds, large beans and tic tac dragees. The results of the tests indicated that particles were not destroyed during the sampling process. Furthermore, the sum total of the sample and bulk weights was equivalent to the input material weight for each of the conveyor feeder versions tested. This suggests that no particles were lost or trapped during the sampling process. Consequently, the conveyor feeders are suitable for the material tested, thereby preventing loss or entrapment of material particles.

Version C was found to produce the most accurate results for coffee beans and pumpkin seeds, with the smallest systematic error. Conversely, version B yielded the most accurate results for Tic Tac dragees, with the smallest systematic error.

The tests conducted with version C of the material type coffee beans yielded the most favourable outcomes overall. This was attributed to the smallest systematic error of only 0.133.

The sample divider facilitates communication with the laboratory environment through the implementation of the OPC UA communication protocol. The OPC UA server and client were developed, as well as a software for controlling electrical components using Arduino. The communication between the server and client is established through an Ethernet cable, while communication between the Arduino and client is established through a serial transmission via USB.

The sample divider employs a sampling protocol that generates representative samples through the collection of small increments of material. These increments are positioned randomly within each window. Each window constitutes one iteration of the sampling procedure, with the windows repeating until all input material has been sampled. This sampling protocol has been optimised by a correction coefficient, which is derived from the difference between the theoretically calculated sampling time and the practically measured sampling time with a stopwatch.

The sample divider was constructed inexpensively and in a relatively short time, which precludes the use of sensors. The incorporation of sensors into the solution would facilitate the feedback for the sample divider, thereby enabling more precise results. This could be a suggestion for future work on the sample divider. Furthermore, as the sample divider is based on a conveyor belt and utilises software to control the sample divider, it is relatively straightforward to produce a representative sample set from the total input material. This can be achieved by sampling each increment into the different sample. This enables a more comprehensive chemical analysis to be conducted, as well as to measure the variance between them.

In conclusion, the adjustable sample divider allows for the production of representative samples of different seeds on a single device, in contrast to the use of multiple, commercially available sample dividers, which are designed for specific sizes and shapes of material particles. This makes a significant contribution to the future development of more precise adjustable sample dividers.

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SYMBOLS AND ABBREVIATIONS

OPC UA Open Platform Communications Unified Architecture

JKI Julius Kühn-Institut

JOH Journal of Open Hardware

TOS Theory Of Sampling

OS Operating System

CAD Computer-Aided Design

IDE Integrated Development Environment

DHCP Dynamic Host Configuration Protocol

TCP Transmission Control Protocol

GUI Graphical User Interface

$\omega_{\mathrm{stepper}}$ angular speed of the stepper motor in metres per second

ω_{steps} angular speed of the stepper motor in steps per second

v linear speed of the transmission belt in metres per second

r_{small} radius of the small transmission pulley in metres

ω_{shaft} angular speed of the shaft in radians per second

r_{big} radius of the bigger transmission pulley in metres

d diameter of the conveyor belt in metres

l length of the straight part of the conveyor belt

N total number of measurements, samples

t_{i} i-th measurement of time

CF correction coefficient

v_{belt} linear speed of the conveyor belt in metres per second

W width of the conveyor feeder configuration

H height of the conveyor feeder configuration

W_{i} weight of the i-th sample

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Electronic appendices of sample divider software including the Arduino software, OPC UA Server and Client: Arduino.ino, opcua_server.py, opcua_client.py

B FreeCAD files of sample divider components

Electronic appendices of 41 sample divider components created in FreeCAD software: Components.zip