Machine Design

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1 Introduction

We started our project by determining the features that we wanted to implement in our sorting machine, like user interaction and exception handling. These design decisions form the foundation of our mechanical machine design. The purpose of this document is to record the design decisions we made in the first stage of the project, from a mechanical point of view as well as a user point of view.

2 Design requirements

In order to create a functioning sorting machine that can sort black and white discs, at least the following components are required.

- A container for storing unsorted discs
- Two containers for storing the sorted discs
- A sensor that can distinguish the different colour discs.
- A transporter that is able to move the discs from the container to the sensor.
- A transporter that is able to move the discs from the sensor to the appropriate container.

3 Final Design

The machine consists of a vertical tube in which the discs can be stored. A pin can be removed from the bottom of the tube, allowing the discs to fall on a platform below, one by one. A colour sensor is attached underneath this platform, such that it can detect the colour of the disc. Next to this platform, a step motor is attached that rotates a wheel with three arms. These arms can push the disc of the platform, either on the left or the right side. Below the platform, a seesaw is attached with both sides of the same length, such that the discs that fall on the platform can fall on these arms. A gyroscope is attached to the axis of this seesaw, such that rotations of the seesaw can be detected. The discs then slide off the seesaw, allowing it to stabilize, and fall into one of two mountable trays.

4 Design Decisions

The machine went through several iterations before we settled on the final design. The decisions that we made during the design process are listed below.

4.1 Position of the colour sensor

We had the option to attach the colour sensor in various ways to the machine. We chose to put it underneath the platform with the sensor pointing up, in such way that the arm of the motor could easily wipe the discs away. Placing the sensor below the discs makes the sensor more reliable, since the surface of the discs on the bottom is larger than the surface on the side of the discs. It would also have been significantly more difficult to mount the colour sensor in a sideways or upright position because of the structural limitations of the lego construction set.

4.2 Container

The decision to use a tube-like structure was made early on, as it is the most compact way to store the discs. The vertical storage also has the added benefit of removing the need to create an additional transporter to move the discs from the container to the sensor, since a new disc will simply fall in place when the previous disc is moved away.

The height between the tube and the platform is designed to be slightly higher than the height of one disc. This ensures that only one disc will be moved from the tube at a time.

4.3 Rotating arm

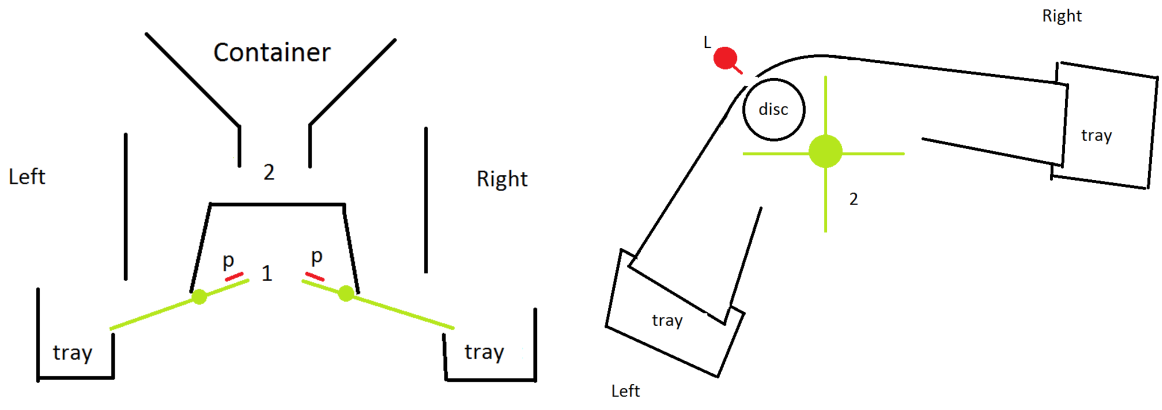
The wheel to which the arms are attached are used to transport the discs from the sensor to the trays. We had options to put 3 or 4 arms on the wheel. We chose to go for 3 arms because then we would be able to attach a touch sensor which is used for calibration.

4.4 Seesaw

Initially, the plan was to use touch sensors to detect if a disc arrived in the correct tray. However, we quickly found that the discs did not weigh enough to trigger the touch sensors. Therefore we finally settled with the seesaw and a gyroscope attached to it.

4.5 Trays

We chose to use coffee cups for the trays in the machine, since these where readily and freely available. Other options would be buying plastic trays or building trays out of LEGO, which was not possible because there was not a sufficient number of parts in the construction set.



(a) Front view (b) Top view.

Figure 1: The initial design of the machine.

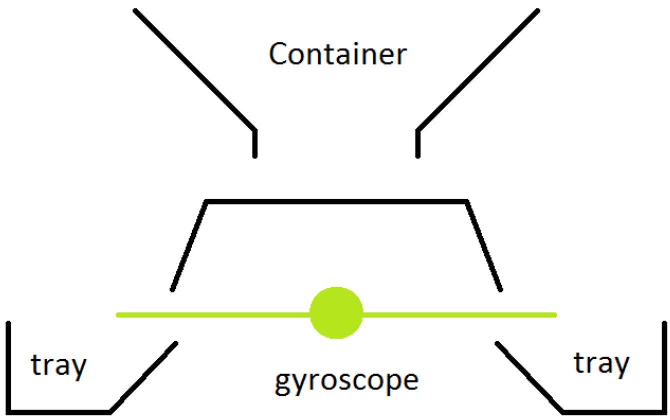


Figure 2: The final front view of the machine.

5 System Level Requirements

5.1 Use Cases

The machine can be described as a finite automaton. This finite automaton is shown in figure 3. The machine has three buttons, which the user can utilize to control the machine. The START/PAUSE button is used to start and pause the machine. The ABORT button is used to stop the machine in case of emergency. The RESET button is used to reset the machine. The user is required to add black or white discs to the container before starting the machine. The machine, when finished without fatal error, produces two trays, one filled with white and one filled with black discs. The machine will also display information about its current state and progress on the display during the sorting process.

The sorting process is described by the following automaton. The initial state is the mode selection state. In this state, the mode in which the machine operates can be selected. These modes are explained further in the document. After the mode has been selected, the machine goes to the initial state of the sorting process. This initial state is the rest- ing state. The user is required to prepare the machine as described in the User Constraints segment further in the document. None of the buttons should have any effect, except for the START/PAUSE button, which starts the sorting process and the ABORT button, which triggers an abort. When this button is pressed, the machine should proceed to the operating state.

In this state, the machine sorts the discs. Internally, it has a state in which it checks the color of the disc, after which it moves to the correct sorting state in which it transports the disc to the correct tray. If the RESET button is pressed in this state, the machine should return to the resting state after finishing its current cycle.

While in the operating state, if the START/PAUSE is pressed, the process should halt after it has finished its current cycle and the machine should go into a paused state. When the START/PAUSE button is pressed again, the machine should return to the operating state at the point where it was when the START/PAUSE button was first pressed. If the RESET button is pressed in this pausing state, the machine should return to the resting state.

While in the operating state, if the ABORT button is pressed or a fatal exception is encountered, the machine should immediately go into an exception state. In this state, the machine must come to a full stop. The machine should only continue when the RESET button is pressed, after which it returns to the mode selection state.

When the machine finds that there are no more discs left in the storage, it should go into a finished state. Then, if the RESET button is pressed, the machine should return to the mode selection State.

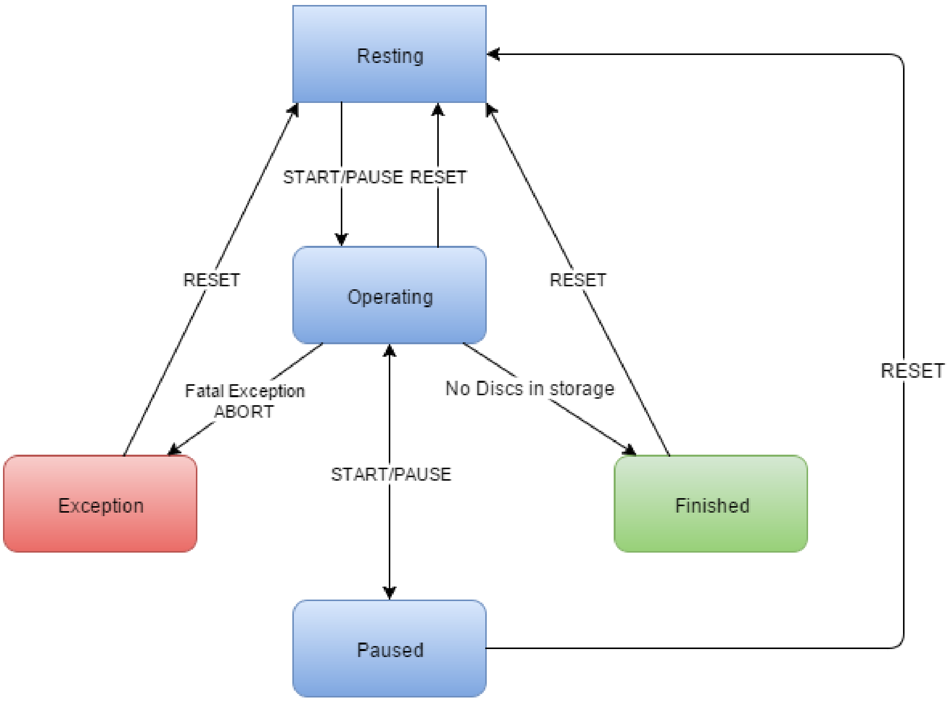


Figure 3: The finite state automaton of the machine.

5.2 User Constraints

5.2.1 Machine Preparation

Before starting the operation of the machine with the START/PAUSE button in the resting state, the user is expected to fill the disc storage with black and white colored discs that need to be sorted. Only discs are allowed in the disc storage and no other objects should be placed in it. The user must also ensure that no discs are present in other parts of the machine and that the disc trays are mounted to their mounting points prior to starting execution. The disc trays should be empty. At most 12 discs may be placed into the container. The user then has to proceed by starting the program. At this point, the machine will calibrate the arm to the standard position. After the calibration, the tube can be filled with discs by pulling out the plug.

After the machine has finished execution, the user will have access to two trays, one containing exclusively white discs, the other only contains black discs. When the machine indicates that it has finished its sorting procedure, the user should remove the trays from their mounts so he can dispose the discs somewhere else.

5.2.2 Exceptions

Possible errors are as follows:

Error type	Fatal (= go to abort state)
Disc does not reach the tray	Yes
Disc arrives in the wrong tray	No
Time to tray is higher than average	No
Wrong input (i.e. different colour disc)	No
Motor jams	Yes
Gyroscope does not stabilise	Yes
Battery low	Yes
Abort by user	Yes
Software exception	Yes

When a disc does not reach the tray, the machine should stop, as there is may be an obstruction in the path the disc takes from the sorting arm to the lever.

When a disc arrives in the wrong tray, the machine should stop, as something happened that caused the disc to move to the wrong tray, even though the sorting arm tried to move it to the correct tray. This means there must be a mechanical failure somewhere. However, because of the limitations the gyroscope and lejos give us, we can not thrust this check entirely. Therefore, we have decided to make this a non-fatal error instead, so the machine doesn't halt in the wrong cases.

The Wrong Input error occurs when a disc is being detected with another color than white or black. This could, for example, be a disc with the color red. This is not a fatal error because we can specify an action that will be taken when this exception occurs. We may for example want the machine to simply put the unknown disc in one of the trays anyway, say default the destination to white, or we dispose all unknown discs into a separate tray.

The machine will give a warning when the battery has less than 5% of charge left. This is done to prevent the machine running out of power in between operations and ending in an invalid state. The user should act appropriately when this happens.

When an error occurs in the machine that is indicated with fatal, the user must remove all discs from all parts of the machine. To help the user with this, the machine has a build-in function that spits out all the discs to the right when pressing the ABORT button in the mode selection state. The user should first make sure this can be done safely and without harming the machine. The user should then press the RESET button in order to put the machine in the mode selection state again. The user may then proceed to prepare the machine for execution again, as described above, if desired.

Safety properties The machine should have the following safety properties. These are our guarantees about the working and stopping conditions of the machine, in case something unexpected happens.

- The ABORT button must stop all moving parts within 10 ms. This to make sure that the user is able to quickly stop the machine in case something can not be handled by the Machine.

- When the machine starts with discs loaded into the container, then the discs will be sorted when it arrives in the finished state. The sorting process takes at most 5 minutes in the default safe mode. However software specification may specify more modes.
- A fatal exception must stop all moving parts within 10 ms. This ensures that the machine does not damage or even destroy itself when it is blocked in any way.

6 Machine Interface

6.1 Lejos API

The Lejos API provides access to buttons on the brick, sensors and actuators. Buttons can be queried directly, but references to sensors and actuators must be instantiated with a Port parameter indicating how they are connected to the brick. The following ports are used in our design:

Peripheral	**Port**
Colour sensor	Port 1
Gyroscope	Port 2
Touch sensor	Port 3
Motor	Port A

Motors expose methods that allow the developer to have to motor rotate an arbitrary number of degrees. Therefore, it is not necessary to implement pulse width modulation. One can call a method to fetch a sample from a sensor in the form of an array of floats. It is up to the developer to parse these in a meaningful way.

6.2 Peripherals

6.2.1 Motor rotating arm

This motor is connected to port A and rotates the arm which moves the discs. The arm has three legs with an angle of 120 degrees. The motor has basically three states: a resting state and two working states, one for every possible direction. The neutral position of the three legged arm is the position where the two arms closest to the place where the disc will land have an approximately identical distance to the disc.

When the motor is in the resting state the three legged wheel has this neutral position. When the motor is in a working state the arms rotate left or right until the next neutral position of the wheel (120 degrees further), where it will transition to the resting state of the motor. During the working state the motor should not be jammed or obstructed in any way, or the motor will be jammed and trigger an exception.

6.2.2 Touch sensor calibrator

The touch sensor, connected to port 3, is attached in such a way behind the sorting platform that the arms of the sorting wheel are able to fully press the sensor when it rotates. This way, it is possible to detect the position of the sorting wheel when it is rotating, which can be used to calibrate the sorting wheel through software.

6.2.3 Gyroscope with seesaw

To the seesaw a gyroscope is attached, which is wired to port 2. The seesaw has three states, a neutral state, a left-side down state and a right-side down state. The neutral state is the state in which the gyroscope when read returns a value indicating that it is in balance. The seesaw enters a left-side down state when a disc falls on the left side. The gyroscope will read a value indicating that it was unbalanced and that the left side went down. This is analogous for the right side down state. The gyroscope is unreliable at best: Its value tends to drift at an arbitrary rate, making the gyroscope unreliable if not unusable in some cases. While the seesaw is in motion no further discs should be sorted, as it will not be possible to accurately measure the angle rate change. Extensive testing suggests, although it is not documented anywhere, that the gyro sensor is much more reliable if one at first calibrates the sensor by quickly switching from rate change mode to angle[1] and back. If the sensor is then kept completely stable, a lower drift rate may be acquired.

6.2.4 Colour sensor

The colour sensor, connected to port 1, gives a value indicating the grayscale of the surface above it. The colour sensor returns a float indicating the grayscale (e.g. 0 uptil 1) of the disc currently on the platform, or the grayscale of the environment, which means that there is no disc above it. After extensive testing, we found that the following values are usefull:

Colour disc	Value
None	0.12
Black	0.15
White	0.86

However, in the mode selection state, these values can be calibrated by pushing the button UP. The user has to put a black disc, then a white disc on the sensor and wait for the program to finish. The values will be changed according to the values found. If no calibration is done, the values of last calibration will be used.

6.2.5 The brick

The brick controls the sensors and actuators. The state of the buttons is either up or down, which may be queried using the Lejos API. The buttons used are shown in figure 4.

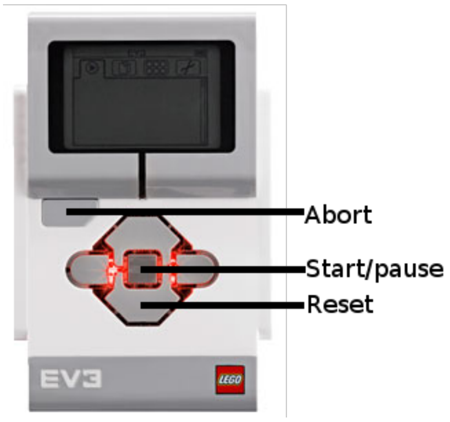


Figure 4: The buttons on the brick.

[1]The gyro sensor has both an angle and a rate change mode, which return the measured angle and the rate of change of this angle, respectively. The angle mode is so unreliable that it is considered unusable for our purposes

7 Conclusion

The design decisions recorded in this chapter will be built upon in the next phase of the project, where we are going to specify the software specifications. The software specifications are heavily dependent on the machine interface described in this chapter, since the machine interface describe our assumptions about the machine API and the mechanical implementation. The software specifications will describe how we are going to use this interface and how the machine will behave.