Engineering Design 4WBB0 2018-2019 Group nr: 279	
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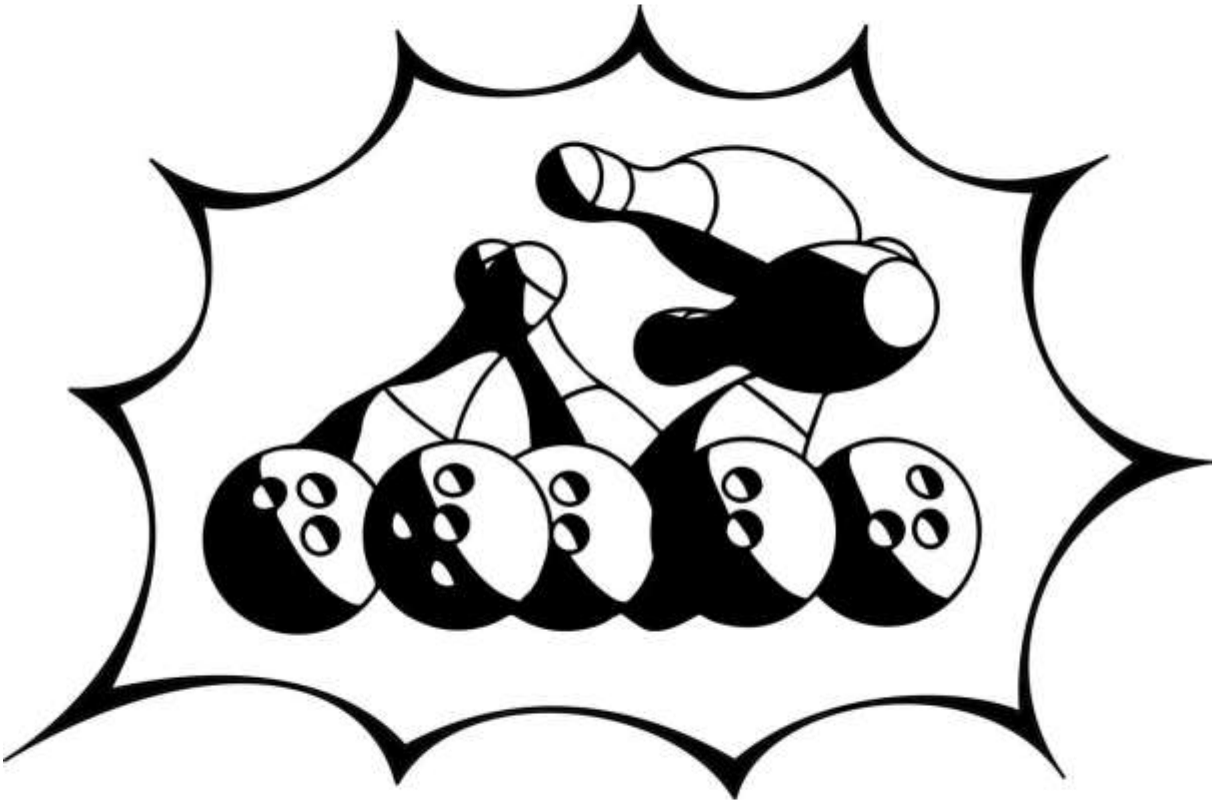

1 Group Effectivity

We are a diverse group. We are diverse in our studies (ranging from industrial- to mechanical engineering and from physics or computer science to industrial design) meaning that we all have different skills that we can bring to the table. It was a big challenge to utilize everyone's skills, yet make sure everyone is also learning new skills and working outside of their comfort zone. This is a careful balancing act: only certain people have the tools, knowledge and materials to perform certain tasks. This can lead to logistic difficulties, but still we often managed: Selwin brought the material and took some people to the mechanical engineering workshop to use some of the heavy machinery, Thijs took his Arduino and electronics kit to the university and lend it out to (beginning) programmers.

This leads us to a major advancement in our group effectivity. For the first few weeks we mostly divided tasks and worked at home. This was very doable: someone made the poster, someone else constructed a prototype, someone did a piece of research or calculation. But since the Preliminary Design Fair we decided to have three-hour meetings every Friday morning in which we can get a lot of work done. This helped us exchange knowledge more effectively and function a lot better as a team. Team members really tried their hand at new skills and learned new things.

There were also times that the group functioned less fluently. Not only are we different in our studies, we also have very different characters. We all have our strong points, weaknesses, challenges and pitfalls and it is not always easy helping each other.

We also have different intentions and goals for this project. It is very notable that there are people who focus more on completing our design, while others are more concerned with complying with course rules and scoring a good grade. Some people are more interested in the course than others. This is an inherent part to functioning within a team, and as long as we are all aware of this and can discuss this, it is a valuable lesson.

2 Project Goal

Billiards is a sport that is widely known in the world and is played on a professional level but also on an amateur level. The sport doesn't necessarily require a lot of physical activity, but one definitely needs to be focused and precise when playing billiards or pool or some other variant of the sport. Playing billiards on an amateur level is done very often in a typical local pub of some sort. In Dutch we call this a ''café sport''. The great thing about this kind of sport is that basically everyone can easily join in on the game and play with their friends. This means such sports have a massive audience.

With this project we will try to make people who lost both of their underarms and can't use their elbow joint anymore play billiards again. This can be achieved by making an arm mechanism that fits on the stub of the dominant arm and a sensor the will be fitted to the stub of the other arm. We have been trying to find a device that lets people without both underarms play billiards, but we were unable to find it. The more reason for us to choose this for our project.

As expected the device is meant to help players on an amateur level to play billiards again. The age and size of the people doesn't matter since we have built in adjustable mechanisms in the arm. This allows people of different sizes to use the device and also benefits the comfort of the device. Other measures to increase the level of comfort of the arm like softening the so-called pocket of the arm will be taken as well. The socket is the part that attaches to the stub of the player. The arm and the sensor will be made as light as possible to make sure the player wearing the device can carry the arm for a significant amount of time before he or she gets tired.

Shooting the ball that is normally done by acceleration the cue through a motion in the elbow is now done by a special device that sits at the front of the cue and is triggered by the acceleration sensor attached to the players arm. The shooting mechanism contains a spring that will be tensioned a particular amount depending on the measured acceleration by the acceleration sensor. When the spring is released the energy will be transferred to the cue which then shoots the ball after which the device resets itself for the next shot. The shooting mechanism is a nicely designed device that contains springs, gears, wire, a servo and a motor that are carefully connected to batteries the power them. This means that once the arm and the sensor are attached to the player with the help of another person, the player will be able perform the right steps in order to fully control the device by itself.

For the sake of letting the disabled users experience the game as if they were not injured at all the device will be programmed in a way that all ''normal'' shooting forces, measured in newton, can be reached by the shooting mechanism. This means the disabled player will not have a disadvantage by using the arm but also not an advantage as that would make the game unfair.

It is important to understand that this project is not only to help people play billiards again, but it is more than that. People with a handicap have surely gone through a very rough time. They are not only coping with their physical handicap but there is also a possibility that it won't feel as they are still a part of the community for them. However, when devices like ours enable them to do the things they used to do with the people they used to be with they won't have that idea of not being a part of society as much anymore.

Since our device will have the shape of an arm people won't have an aversion against the device as quickly since having an arm is regarded as normal in the human mind. This means that the shape of the device will psychologically have a beneficial effect of the way people look at it thus it is more user friendly which is very good since a friendly appeal is one of the goals of this project.

Letting people with the described injuries play billiards again is obviously the ultimate goal. However, in order to achieve that we set a number of smaller goals for our group during the whole process. We can roughly divide the goals in a couple of categories. As mentioned above the appeal of the device was one of them. But another very important goal was to make the arm as comfortable as possible. Comfort is a wide term and the things we have taken into account in order to more the arm comfortable are: weight, size and the grip of the stub and the convenience of using it. The weight of the arm was an important step of reaching our goal of comfort. We basically did two things to make sure the weight of the device was not going to be a problem. We used aluminum to make the frame of the arm. Since aluminum is a strong but lightweight material we reduced the weight quite a lot by using it instead of for example wood. The other thing we did is not something to reduce the absolute weight of the arm, but it surely makes it easier for the player to hold the arm. Namely, the mechanism that sits at the front of the cue now has feet, or a so-called bipod. The feet have grips under them to make sure the shooting mechanism will not slide away when shooting but also to make sure the billiard doesn't get damaged. Keeping the size to a minimum was also a fun but challenging goal to work towards. Our project is not necessarily small, but we had to come up with some clever ideas to make sure it fits into the box. The last goal that was set to achieve maximum comfort was optimizing the pocket. Since this is one of the few parts that is actually attached to the player it was important for us to make sure it was done right. The pocket should be comfortable and soft for the sake of the player but also provide a firm grip to increase controllability and safety.

We obviously did not only set goals for comfortability. As important as that is, the player should be able to be competitive with the arm as well. This brings us to our next goal which is optimizing the mechanical components and shooting mechanism to reach powers that can be compared with normal shooting powers. Arguably the things we have spent most time one. Along the process we found out that recreating human strength is not as easy as it sounds. Especially not when you have to a particular budget into account.

The final overall goal was to keep everything under the budget. Luckily, we were able to get the extra budget but even with that it was still a challenge to make such a complex device within the budget.

Combining the goals of comfort and competitiveness all within the budget we achieved our ultimate goal which is to make a device which enables people who lost both of their underarms to player billiards again.

Obviously, the main goal of this project was to create a device that checks the boxes and is a pleasure to use. However, as far as I know this can only be achieved by good teamwork and communication. Perhaps it was not our initial goal to work on these skills but we sure as hell did and improved a lot on them. Working in a team requires essential skills that come in handy later on. As said it probably wasn't the initial goal but we all surely improved as far as working in a group goes.

3 Functions and Solution Encyclopedia

Comfort and adjustability	Elastic sleeve Soft lining on inside of the sleeve Sleeve makes use of belts to adjust width Easy to carry by disassembling Light weighted Freedom of movement Compact Safe Silent so the player can keep his focus Useable for different persons Adjustable in angling the cue Adjustable in length

Striking	A striking mechanism that is part of the cue A striking mechanism that is part of the arm (so different cues can be used) Triggering the strike with a muscle movement Not making use of a typical cue but using a self-made object that strikes the ball The space where the strike happens is visible Tensioning a spring Tensioning elastic bands Using hydraulic pressure Using pneumatics Using magnetism A mechanism according to the rules of the sport

Sensor	Converting muscle tension into striking force Pressure sensor in the sleeve to measure muscle activity A strap connected to the shoulder A sensor that is voice sensitive

	Pushing with foot A sensor that measures the distance between the cue and the ball A sensor that measures muscle impulses with electric signals Movement of the head Eye tracker Making a turn with the whole body Acceleration sensor

Striking direction	A stand that follows the movement of the arm Cue is attached to the person's waist and there is a webcam on the cue, so the person still can have a regular view on the ball Angling with the same arm which holds the cue A holder attached to the person's waist where the person can put the cue in A two-step mechanism: firstly, angling the cue, and secondly, determining the force A holder on the table where the cue can be put in (sort of already exists) A second prosthetic on the other arm which has a holder attached to it Angling the cue with placement of foot A sensor on the second arm that determines the angle and/or direction

4 Concepts

For the third meeting, each group member has made a 'shitty prototype' to explain the group what concept they had in mind. We as a group discussed all the shitty prototypes and eventually made a decision for our preliminary design. In this chapter all these 'shitty prototypes' are discussed.

Prototype 1:

In this prototype the cue is attached around the middle of the user. The user can move the cue (and thus aim) with ropes attached to both arms. On the tip of the cue a camera is attached so the user can see where he will hit the ball. This camera is used so that the user will have the same experience as a without a disability, because the sight of a player without a disability is in line with the cue. The shooting of the billiard ball will be done by magnetic repulsion. This shooting mechanism consists of a permanent magnet and an electromagnet. With an acceleration sensor attached to one arm, the shooting force of the mechanism will be determined. When the ball has to be shot, a current will run through the electromagnet. The electromagnet will repel the permanent magnet which is attached to a stitch to hit the billiard ball. The amount of current through the electromagnet will be determined be the acceleration sensor. In the picture on the right, the shitty prototype is visible with all the parts named.

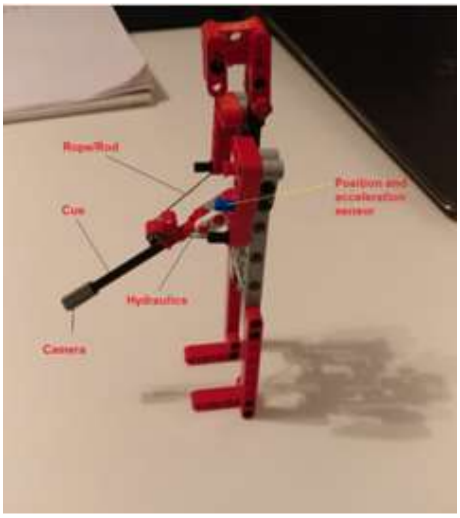

Figure 1 Prototype 1; cue attached around middle

This prototype is quite easy to control, but it will require some muscle strength to control the cue. A solution to this can be that the ropes are changed with a hydraulic system. This will solve the problem and it will be a creative and elegant solution, but it is a lot more complicated and it will be a lot more expensive.

Prototype 2:

Figure 2 Prototype 2; mechanical arms attached to pool table

The second prototype consists of mechanical arms attached to the pool table. The cue will be held in the air by these arms and it can be finely adjust by the user by using his residual limbs. The arms will become rigid when there is no force exerted on the arms. The arms can move around the table by the user by using his residual limbs. The ball will be hit by the cue by using a motor in one of the arms of the mechanism. The power of this motor will be controlled by pedals placed under the pool table. On right a picture of the prototype is placed.
This is a simple solution for the problem, but it will not meet the constraints because it won't be able to fit in a box of 30x30x50cm and it will probably weigh more than 3 kg.

Prototype 3:

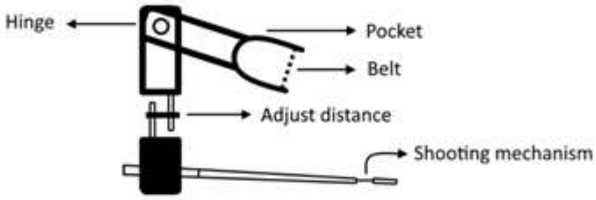

Figure 3 Prototype 3; robot arm

The third prototype is the so called 'robot arm'. The idea of the robot arm is to replace the missing arm of the user in such a way that the way of playing billiards feels as natural as possible. The arm consists of a sleeve for the limb to attach the robot arm to the user. To the end of the sleeve a hinge is attached to replace the elbow joint. Attached to the hinge the 'lower arm' is placed. This lower arm should be adjustable in length so that users of different (arm) lengths can use this device. At the end of this lower arm, the cue will be attached. The shooting of the ball will be done by a separate part. This shooting mechanism will be placed at the end of the cue. The mechanism can be made in several ways, for example: springs, air pressure, hydraulic pressure or magnetic repulsion. The idea is that the shooting will be triggered by a sensor. An example for a sensor can be a pressure sensor in the sleeve. The pressure sensor can be activated when the muscles in the upper arm are contracted. This contraction of the muscles can then trigger the shooting mechanism. This prototype is also made schematically visible in the picture on the right.
In this concept, all the functions have been taken into account. It is a user-friendly and creative design to aid our projected users. However, this idea is very ambitions given the imposed constraints and it may be a quite complicated prototype to make.

Prototype 4:

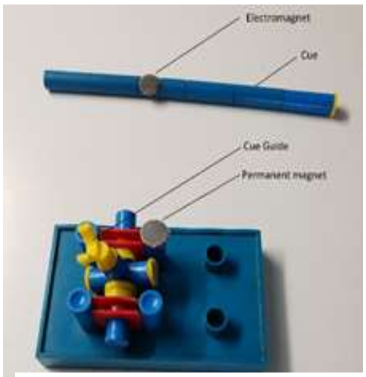

Figure 4 Prototype 4; cue guide

In this prototype, the main focus was on helping the user to aim the cue. This prototype is the so-called 'cue guide'. The cue guide consists of a half circle attached to a block to guide the cue. This halve circle can move up and down and it can rotate 360 degrees. To move the cue guide around the table, magnetic attraction is used. A permanent magnet is attached to the cue guide and an electromagnet in the cue. This electromagnet can be turned on by using a pressure sensor attached to the arm of the user. The pressure sensor can be activated when the muscles in the arm are contracted. When the muscles in the arm are contracted, the electromagnet in the cue is turned on and the cue guide is attached to the cue. A picture of the cue guide is shown on the right.
The cue guide is not quite an innovative or creative solution, but it is humanitarian and elegant solution for disabled cue sports players, because the concept already exists but it is not as extended as the cue guide.

Prototype 5:

The prototype consists of a platform, with wheels beneath it. On top of the platform is a 'pillar', the cue is connected to that pillar. To let the user use the cue, tube-like arms are connected to the cue. The user will be able to put those on and in this way use the cue. On the back of the object, you can find a position sensor, the user is also wearing a sensor. This means, that when the user moves around the table, the object will follow the user. This makes the concept autonomous. To get this working, the object will need some sort of motor to move the object around. The (not yet finished) prototype is shown in the picture on the right.

Figure 5 Prototype 5; moving platform

This is a very innovative but complex prototype for the design. Besides that, it will be nearly impossible to let the prototype meet the constraints of fitting in a box of 30x30x50cm and weigh less than 3 kg.

Prototype 6:

This prototype consists of two parts, one part for replacing the 'shooting arm' and one part for replacing the 'aiming arm'. The first part consists of a sort of prosthesis which can hold and fire the cue. This prosthesis is attached to the arm of the user by a belt so people with different arms can use it. Then the prosthesis also has a sort of joint to replace the elbow. This joint is free, so the cue is always perpendicular to the prosthesis and parallel to the pool table. The prosthesis is also adjustable in height, so users of different heights can use this device. The cue can be attached to the prosthesis with a click mechanism. The cue can be placed on the prosthesis in different ways depending on the preferences of the users. At the point where the cue is attached to the prosthesis, a shooting mechanism is installed, this mechanism can be activated be moving your arm. The second part resembles the first part, because it is also a sort of prosthesis. This part is an extension of the arm with a holder placed at the end to aim the cue. These parts are shown in the pictures below with the first part on the left and the second part on the right.

This is a simple solution for disabled people who still want to play billiard, but the concept is no very elaborated because the way the shooting mechanism works is not clear. Besides, this concept won't meet the constraint because there is no sensor being used.

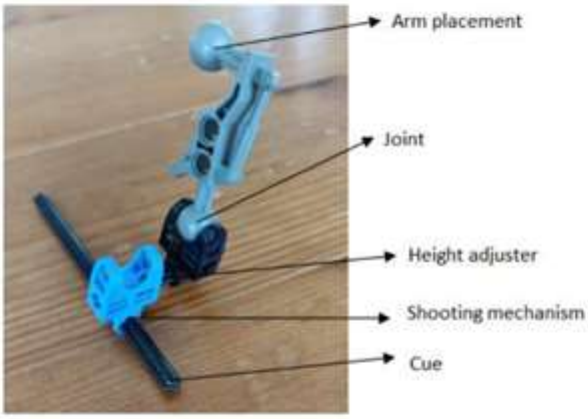

Figure 7 Prototype 6 Part 1; cue holder

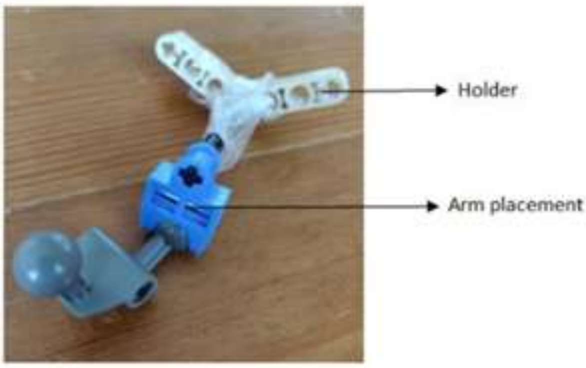

Figure 6 Prototype 6 Part 2; cue aimer

5 Requirements, Preferences and Constraints

Requirements

The Robot-arm must be strong	The Robot-arm must be able to carry 1500 g
Users of different length can use the Robot-arm	The length of the lower arm is adjustable between 25 and 50 cm.
The shooting mechanism is powerful	The shooting force must be between 0.1 and 60 N

Preferences

The Robot-arm should be comfortable	Making use of soft materials
Users with different circumferences of the upper arm can use the Robot-arm	Making use of belts to attach to Robot-arm to the user
The user should be able to focus	Make the design simple and not to colorful
The Robot-arm should be easy to adjust	The cue should be loosened and fastened as fast as possible
The Robot-arm should be easy to wear	Make the Robot-arm as light as possible
The user should have the same experience as a non-disabled billiards player	Making the Robot-arm in such a way that de user has the posture as a non-disabled billiard player
The user can play at his own pace	The time between two shots should be as short as possible

Constraints

The Robot arm must be autonomous	Making a shooting mechanism where the shooting force depends on the acceleration measured by the acceleration sensor
The Robot arm can weigh maximal 3 kg	Making use of aluminum
The Robot arm must fit in a box of 30x30x50 cm	Using a hinge and a separate shooting mechanism
The Robot-arm must have a sensor	Making use of an acceleration sensor
The Robot-arm must be save	Preventing that there are any sharp pieces, using soft materials

6 Preliminary design

As seen in the pictures, our preliminary design consists of multiple parts that are connected to each other. The preliminary design consists of a sleeve, a part that will be connected to the cue and a hinge that will act as the elbow. The mechanism that will shoot the ball will be connected to the cue.
The sleeve is the part where the stump of the user will be put in. It will be a fit-for-all sleeve such that everyone is able to use it.
The part that will be connected to the cue will do just like it says; it will hold the cue. Because the user is missing one or both arms, this is necessary. When the cue is connected the user is able to move around with it and start playing billiards.
The hinge in the preliminary design acts as the elbow of the user, it will make it possible to be standing like the 'normal' billiards players and it will make aiming with the cue much easier.
The shooting mechanism will be triggered by an acceleration sensor. When the user makes a movement with his other arm, the mechanism will calculate a certain speed and will then shoot.

Our design is made up like this because of multiple things. First of all, one of the main musts is that the device is user-friendly. Therefore, we want the sleeve to be fit-for-all, feel nice, and not feel very tight. It should feel like you are wearing a shirt and are holding a bag of groceries. But instead of that, it is the sleeve with the cue connected to it.
Also, something that has to do with user-friendliness but is not included in the preliminary design, is the possibility to change the height of the arm. The part between the sleeve and the part that will hold the cue will be able to be adjusted in size. What this means is that for taller, or smaller people, the arm can be adjusted to their needs. By doing it like this we will make it a device that can be used by a lot of people.
The part that will hold the cue is also developed in a certain way. Because you will never know where the ball will end up, you might need to extend the cue, or do the opposite. Therefore, it is needed to make it possible for the cue to be connected to arm in different ways. In the preliminary design it is possible to connect the cue at different positions, so it will always be possible to hit the ball at the right angle and position.
The hinge that will act as the elbow is very important in this design. By simulating the elbow, the user will get much more freedom in the usage of the device. The user will be able to aim much better and move the cue and the arm with much more ease.
The shooting mechanism is a very important part of the whole product. Without it, the user would not be able to play billiards. The preliminary design is made in such a way, such that the user does not have to play billiards like 'normal' users, the user will not have to move the cue while playing. First of all, if the user would have to move the cue, the user would have to move the whole arm, that would be tiring, heavy and not accurate. By using the shooting mechanism all the user has to do is aim with the cue and make a movement with his/her other arm (or stump).
After the development of the concept products, this design was chosen to be used as the preliminary design. Other concepts that could have been the preliminary design are a device that is connected to the table and can move around it, playing billiards with both stumps, a movable stand with the cue on it or a cue around the waist.
Like already had been mentioned at the start of this topic, user-friendliness is very important. Other priorities for the design are the RPC's.
In comparison to the other concepts, this one is very user-friendly. The device that can move around the table is, in comparison to the chosen preliminary design, not very user-friendly; it would require someone else to move it when necessary, this is also the case with the movable stand around the table. The usage of

two stumps would require the user to do much more, which can be difficult for some users. A cue around the waist will make it not seem like playing billiards anymore, it will also be in the way most of the time, which does not make it user-friendly.
It is also the case, that the other concepts do not fulfill the RPC's. The device around the table is probably not autonomous, it would also have to fit in a box of 0.3x0.3x0.5 m^3, which it probably does not. Another thing is the weight, which needs to be three kilograms or less. This also applies to the stand that moves around the table, it is way too big, it will probably weigh more than three kilograms and it is not autonomous.
Because these two concepts do not fulfill the RPC's and the other two concepts would be much less user-friendly than the chosen preliminary design, therefore the design was made like this.

The chosen preliminary design does fulfill the RPC's. This device can carry a cue, it will be possible to adjust the height in a later stage of the design and the power of the shooting of the ball can be calculated and chosen by the user by means of swinging the other arm (or stump) faster or slower.
This preliminary design is autonomous, it will not weigh more than three kilograms because it will be made out of aluminum, which is very light. Because the device can be folded at the hinge, it is possible to fit it in a box of 0.3x0.3x0.5 m^3. It will also use an acceleration sensor that will make the shooting of the ball happen.
Because of the reasons above, this design was chosen.

Figure 9 From left to right and top to bottom: 'Elbow', cue connection, full picture, folded arm, sleeve

Figure 8 Shooting mechanism

7 Risk management

Topic What may happen?	Probability How likely is it?	Impact What does this cause?	Control How do you prevent it?
Acceleration cannot be converted accurately to the force that the cue will strike with	Quite likely	The force of the strike of the cue cannot be controlled	- Use a more accurate sensor - Use a different striking mechanism
The arm cannot hold the cue	Not likely	Cue cannot be used	Change the holding mechanism
The length cannot be adjusted properly	Not likely	The robot arm is not suitable for everyone	Make changes in the length adjustment mechanism
Costs of the components are too high	Not likely	The robot arm cannot be assembled while sticking to the budget	- Choose other components or eliminate unnecessary components
The robot arm does not	Not likely	The person cannot	- Make use of belts that

attach well to the person's arm		optimally make use of the robot arm	can be tightened well - Make us of Velcro fasteners
The shooting mechanism creates too much recoil	Not likely	The person cannot use the arm comfortably	Use small forces
The acceleration sensor doesn't work properly	Not likely	- The sensor does not detect the right acceleration, so the eventual force of the striking mechanism makes no sense - There is no detection of acceleration at all so the arm mechanism is not triggered	- Use a different acceleration sensor - Change the system that determines the force in the striking mechanism
The shooting mechanism placed on the cue is too heavy	Not likely	- The cue leans forward which creates an impractical angle	- Use different materials for the mechanism - Change the mechanism - Locate the mechanism in another place on the arm
The shooting mechanism cannot create a force big enough to make a strike with the cue	Quite likely	- The person cannot make a strike with the as hard as regular players can	- Use another mechanism - Use stronger magnets
The frame of the arm is not strong enough to hold all components	Not likely	- The robot arm cannot be used	- Change the structure of the frame - Use different materials
The hinge is too weak	Quite likely	- When the person makes a move with the robot arm, the cue keeps swinging a bit	- Make some resistance in the hinge

8 Detailing

The shooting mechanism

A lot of thinking was done on how to work out the shooting mechanism. The global idea is pretty simple. A motor is needed to spin a pulley that winds up a rope connected to a spring. However, the problem that was encountered was that the rope should be able to unwind very fast when there is no force applied anymore. Unfortunately, the motor has a large resistance when you want to spin it freely. Even when it is turned off.

To explain the solution for this I first have to explain the complete shooting mechanism. The challenge is to build a mechanism that can store the energy of the motor for a particular time to release the buildup energy instantly whenever you want. To achieve this there are two states in which the mechanism can be. Basically, one state enables us to tension up a spring and the other one allows us to release the whole system. Both states are worked out in more detail below.

The first state of the mechanism is the state in which the two gears (numbers 3 and 4) are connected. This means that whenever the gear (number 4) is spinning the other gear (number 5) will also spin. The first gear (number 4) is driven by a motor (number 1). This motor provides a particular force. This force passed through by the gear (number 4). The magnitude of the torque depends on the diameter of the gear. These details of the gears are worked out below. The spinning motion of the first gear (number 4) is passed through to the second gear (number 5) which then makes a pulley (number 6) spin. A rope (number 8) is connected to this pulley which means that whenever the motor is spinning this rope will be rolled around the pulley. The rope is connected to a spring (number 9) that is tensioned up when the rope is rolled around the pulley. The spring (number 9) is connected to a cue (number 10) which is pulled back by the rope. The motor spins a particular amount of time. The longer the motor spins the harder the cue shoots when it is released.

When all the earlier mentioned steps are done the cue the system can be released to make the shooting motion possible. This is where the second state of the mechanism comes into play. The second state allows the energy that is stored in the spring (number 9) to be converted into kinetic energy that drives the cue (number 10) forward. The system is released whenever the two gears (number 4 and 5) are not connected anymore. This was done by installing a servo (number 2) into the mechanism that can control the position of the gear (number 5). The lever of the servo (number 2) can change position which results in a change in position of the gear (number 5). Basically, by activating or deactivating the servo, the gears (number 4 and 5) are connected or not connected. The piece that is attached to the lever of the servo has a 90-degree corner in it. This had to be done to increase the distance between the servo and the motor. Since the diameter of the gears were too small to both fit the servo and the motor directly to the axis of the gears a detour had to be made that connects the gear (number 5) to the servo.

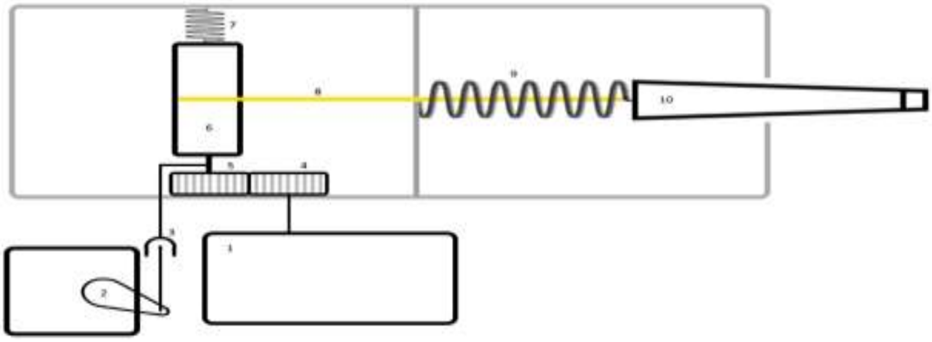

Figure 10 State 1 of the shooting mechanism

When the first state of the mechanism has done its job and the spring (number 9) is tensioned the lever of the servo (number 2) will move in a position causing the two gears to disconnect. When the gears are disconnected the gear (number 5) can spin freely which allows the rope to unroll from the pulley which results in the spring pushing the cue forward. When the servo is then deactivated, a spring (number 7) pushes back the pulley and the gear which results in the gears connecting again which brings it back to the first state of the mechanism ready to tension up the cue again. The motor is programmed in such a way where the gear (number 4) spins, when the gears are disconnected, to a particular position in which the teeth of the gears will not hit each other when they are connected again.

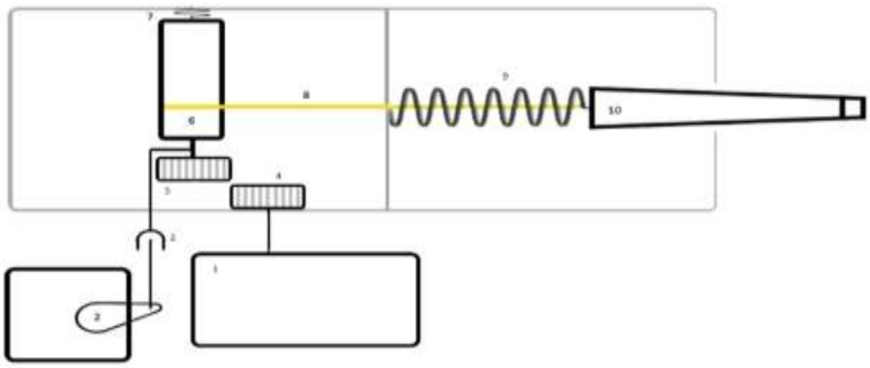

Figure 11 State 2 of the shooting mechanism

The arm

The details of the arm will be explained, starting from the top of the arm, where it is attached to the limb of the player. The attachment part of the arm consists out of four aluminum strips (figure 1, number 1) these are held together by two aluminum rings at the bottom (figure 1, number 3). The aluminum strips can be tightened up by fastening the belts that go around the top of the strips (figure 1, number 2). These belts are attached to the metallic strips. The inside of the strips consists out of a soft material which makes for a comfortable sleeve for the player.

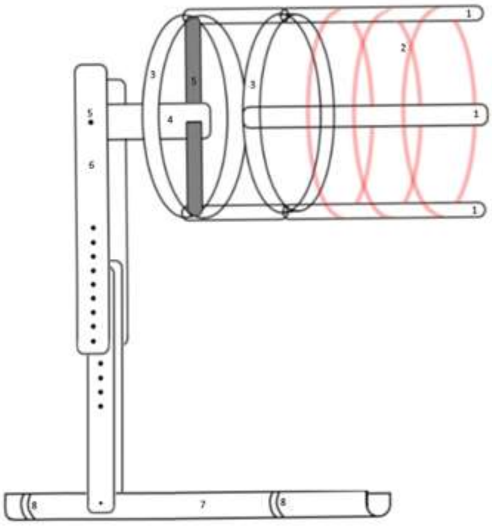

Figure 12 The arm

The hinge mechanism. This is the mechanism that will force the ''under arm'' to always hang straight down. This hinge mechanism has to be able to pivot around two axes, counteracting the movement of the limb (figure 2). The hinge consists out of one aluminum square tube (figure 1, number 4) with four holes in it that enables two round rods (figure 1, number 5) to go through the square tube (figure 2). One of these rods is connected to the upper arm, the other is connected to the lower arm. This makes a turning motion in two different directions possible, while the arm will always hang straight down.

The under arm consists out of four aluminum strips (figure 1, number 6). These strips can be connected by bolts, the length of these strips is adjustable. This is possible by making multiple holes in each strip so that the position of the bolts can be changed. The strips are connected at the bottom to the cue holder. The cue holder is made out of a PVC tube (figure 1, number 7) and uses two metal tyraps (figure 1, number 8) to attach the cue to the holder.

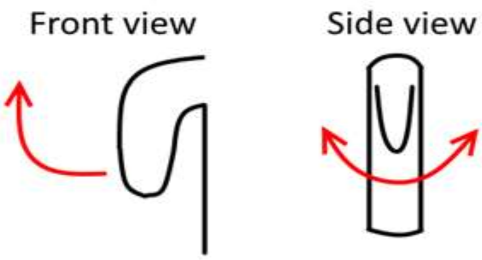

Figure 13 Front and side view of stump

Electronics

The electronics part of the whole system starts at the acceleration sensor. This sensor is attached to the players limb that is not attached to the arm. When the player makes the movement with its arm to determine the power of the shot the acceleration sensor will measure a particular acceleration. This number is sent to the Arduino (Figure 3, number 1) where it is converted to a particular amount of seconds that depends on the measured acceleration. Then the Arduino will let the motor spin for the amount of seconds that was determined before (Figure 3, number 3).

Once the motor is done spinning the Arduino will have to receive a measured acceleration above a particular number before it activates the servo. This is done so that the player can not only determine the power of the shot but also the exact moment the shot will be taken. If the acceleration sensor will measure an acceleration that exceeds a predetermined number the Arduino will activate the servo (Figure 3, number 2) which means the lever of the servo will change position. This change in position disconnects the gears which enables the rope that is attached to the spring to unroll freely and cause the cue to shoot.

Once the shot is taken the Arduino will ''tell'' the servo (Figure 3, number 2) to slowly move its lever back into its original position. While this is done the gear that is attached to the motor will spin slowly. This will decrease the chance that the teeth of the gears hit each other when the gears are connected again. Once the gears are connected the motor will stop spinning. The whole process is then repeated when a new acceleration is measured by the acceleration sensor and sent to the Arduino.

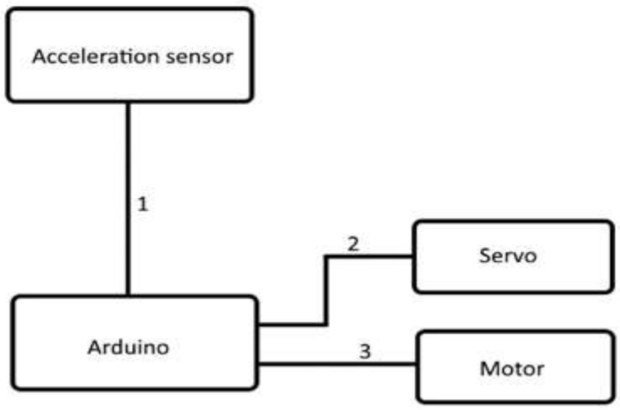

Figure 14 Connection diagram

9 Assembly

As assembly was started, we immediately ran into some problems. An electromagnet and a permanent magnet had been ordered and our calculations showed they would be able to attract and repel each other at forces that would be big enough to strike a billiard ball. Tests showed however that the magnets would attract each other no matter the voltage through the electromagnet. (For more on this, see *"Test plan: shooting mechanism with magnets"*). This means the concept which we had settled on while building the preliminary design had to be changed and we part of the process had to be started from scratch again.

Regardless of the technicalities of the shooting mechanism, assembly could start on another part of our design, the arm. How our prosthetic arm would fit together had already been thought out. The plan that can be seen to the right was made by Bas and Selwin for SSA 6.

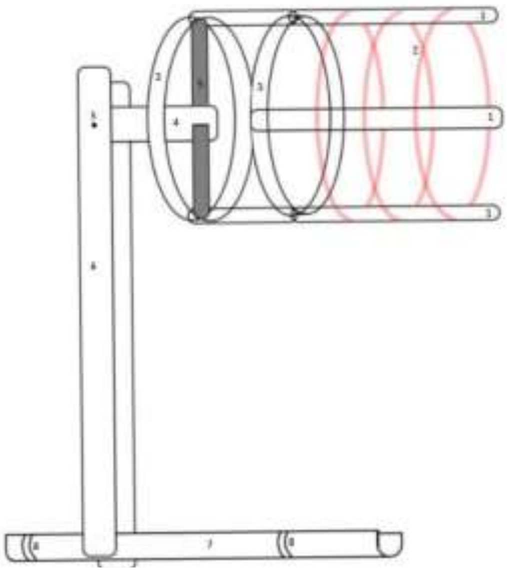

Figure 15 The arm

Aluminum strips and rings were bought. In the mechanical engineering workshop, the aluminum strips were cut into the right lengths and drilled. When drilling and sawing aluminum it was found that some flash and raw edges were created. Those were gotten rid of using files and sanding paper.

What is not included in this plan is the mechanism for adjusting the length of the strip marked “6”. This had already been discussed in earlier meetings: a strip was sawed in half and holes were drilled every centimeter.

Next, the shooting mechanism was redesigned to the design we finally made. With this, the code was also rewritten to fit the current mechanism. Work on the arm meanwhile continued. Straps were added that would allow the arm to be fitted on the residual limb of the player comfortably, and everything was fitted together with nuts and bolts for the first time.

By the time of SSA 11, the new shooting mechanism had been assembled with a motor pulling a spring back (more on this in the chapter on detailing).

Figure 16 The sleeve

Figure 17 The adjustable under arm and the 'elbow'

This design was then tested, and it was found that the tip would not be pulled back as calculations showed it should, but that the force from the current maximum spring tension would still be ample for our purposes. Next, the sleeve was modified: a soft lining was added as per the RPC’s, and the fastening method was slightly modified to make it more effective.

A “hand” was constructed out of a small pvc pipe and hose clamps to attach the cue to the arm. And everything was assembled once more.

Figure 18 Shooting mechanism

Figure 20 The sleeve

This iteration of the arm is very close to the final design and only needs to have the wiring and electronics fitted.

While this was being finished, work also continued on the shooting mechanism. It needed to be assembled to the cue and it needed legs for it to be able to support itself on the table.

As with the arm, the shooting mechanism went through various iterations before reaching a satisfactory state. It had been determined by the group that the shooting mechanism would be secured to the cue by means of hose clamps.

Figure 21 Holder of cue

Figure 22 Shooting mechanism

Initially, they were glued in place. A dremel tool was used to drill and sand grooves into the aluminum to give the glue some more surface to stick to. Glue proved not to be enough to hold the clamps in place however, and a redesign was needed. Finally, the clamps were bolted into the aluminum.

Figure 23 Full arm

The support for the shooting mechanism was first constructed out of wood, but later redone in aluminum, to give the entire mechanism the same overall look. During the final tests of having the mechanism shoot a billiard ball, it was determined that the supports were a bit high, and they were bent into a more appropriate shape that allowed more accurate aiming and more efficient energy transfer between cue tip and ball.

Figure 24 Bottom of shooting mechanism with stand

Figure 25 Bottom of shooting mechanism

The very small servo motor that was bought did not work during tests. It was unable to push in on the mechanism once there was tension on it, so a bigger, more powerful servo was bought, tested and secured onto the mechanism.

Some finishing touches were added in the form of a proper cue tip atop the shooting mechanisms business end and with that our design was as good as assembled.

10 Final Design

Bill of materials

Number	Component	Supplier	Amount (euro)
1	4 aluminum strips of 20 cm	Aluminiumopmaat	2.02
2	4 bicycle straps	Gigabikes	2.95
3	2 aluminum rings with 12 cm diameter	Aluminiumopmaat	2.93
4	Aluminum square tube of 5 cm	Aluminiumopmaat	1.21
5	4 aluminum strips of 70 cm	Aluminiumopmaat	2.40
6	4 hose clamps	Gamma	2.49

7	DC 6V 1 rpm reversible high torque turbo worm geared motor DC motor GW370	Banggood	7,97
8	Compression springs	Sodemann industriele veren	13.09
9	4x AA Battery	Karwei	4.49
10	4x AA battery holder	NKON	1.50
11	Arduino Uno + Starters set	WillieWortel.eu	14.41
12	MPU-6050 acceleration sensor	Tinytronics	5.00
13	MG996R Servo	Tinytronics	7.00
14	TIP31C Transistor 100V 3A	Tinytronics	0.50
15	Diode	Tinytronics	0.15
16	PCB	Conrad	0.80
17	Electric wires	Gamma	1.00
	Total		69.91

Manufacturing techniques

Component number	**Manufacturing technique used on the components**
1, 3, 4, 6, 7	- Drilling - Sawing - Fastening with nuts and bolts
12, 13, 14, 15, 16	- Solder

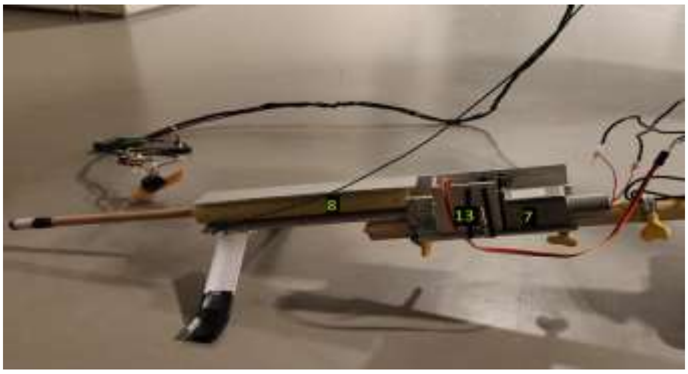

Figure 26 Shooting part; contains servomotor (13), dc motor (7) and spring (8)

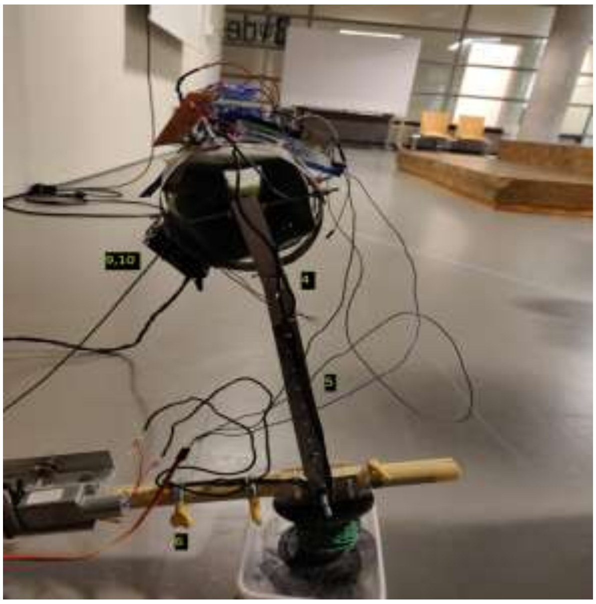

Figure 27 Frame of the arm; hose clamps (6), aluminum strips (5), hinge (4), batteries and battery holder (9,10)

Figure 28 Aluminum square tube

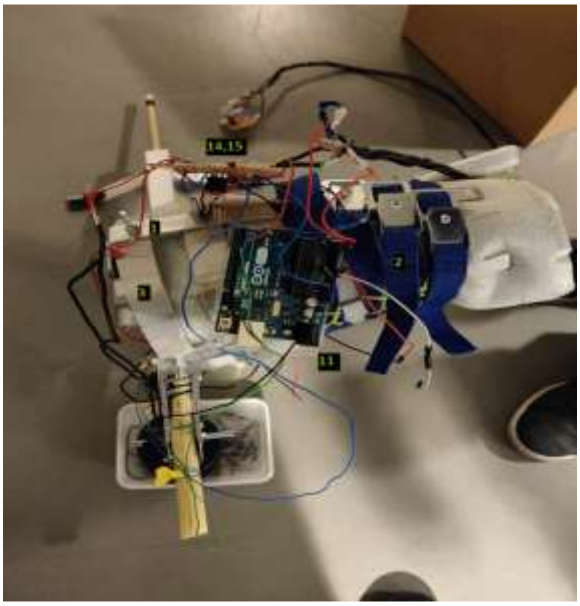

Figure 29 Sleeve; bicycle strips (2), aluminum rings (3), aluminum strips (1), Arduino (11), transistor (14), diode (15), PCB (16)

11 Test Plan

Arm

Since the arm is by far not as complicated as for example the shooting mechanism, the test plan will be a lot simpler. Also, no tests can be run to calculate. Testing the arm is basically a practical experiment without any calculations.

Goal

The goal of the experiment will be to test the arm in a way that gives us insight in what areas it performs as we want and in what areas it does not. The areas I am talking about are globally strength and comfort.

Theory

I'll start at the top. The player will attach its limb to the arm via the so-called socket. This is a part of the arm which basically consists of a hole that is soft on the inside and contains belts on the outside to tighten it up so that it will fit different people. Making the inside soft so that the player can comfortably wear the arm is a very important element of the arm.
We assume (yet to be tested) that the arm itself will be strong enough to withstand all the forces. All the parts of the arm are completely made out of aluminum which is a light but also strong material. Nevertheless, testing will be other to not only check whether the arm holds up but also if the player can still comfortably wear the arm when forces are applied. Think of the kickback on the arm when the shooting mechanism shoots a ball. Is it then still going to be a comfortable experience?
The hardest part of the arm was to create a simple yet very effective hinge. The hinge is located where normally the elbow joint sits. We figured that it should be a two-directional hinge to make sure the ''underarm'' always hangs straight down. The hinge should be able to compensate for abductive and adductive movements, but also for flexion and extension of the upper arm. (Figure 1)
The hinge consists out of an aluminum tube with holes in it so that two axes can fit right into it. (Figure 2)
Last but not least the underarm will be adjustable in length to compensate for different heights of people. The adjustable mechanism is a simple one. The aluminum strip that make the underarm can slide besides each other and can be attached to each other with screws that go through holes in the strips. Indicated with the red circle. (Figure 4)

Hypotheses

The arm can be expected to provide comfort throughout different motions when different forces are applied.

Experimental setup

This is perhaps a bit silly for the arm but for the sake of consistency it is perhaps good to write how we are going to test the arm. First of all, it is necessary that most, if not all, group members should wear the arm for some time. This is important to test the adjustability of the arm for different people with different arm sizes. While wearing the arm, the player should fully rotate its shoulder in every possible direction to see if the under arm will always hang down no matter what the position of the shoulder and the upper arm is.
The next important thing to test is the comfort of the arm while shooting the ball. The kickback that the shooting mechanism will give should not be too harsh on the players arm. I suggest we should a couple of times on low and maximum force and see how it holds up.

List of materials

- 3 belts
- Foam rubber
- Aluminum parts
- Hinge
- Screws
- Shooting mechanism

Results

There are of course no numerical results that I can give but the mechanical arm is completely finished, and we have all worn it to test the comfort and the movements of the arm. We all agreed upon each other that the mechanical arm sits nice and tight around the arm and all movements are translated in the way we imagined it. However, being in full control of all the exact movements the mechanical arm will make when the player moves its arm will require quite some practice.

Conclusion

One will be able to master the movements of the mechanical arm if enough time has been put into practice.

Discussion

Although the arm works well there are a couple of negatives to it. First of all, when the arm hangs down with a particular angle all the movements in the sideway direction will be fast and big due to the weight of the underarm that is being swayed from one direction to another.

Also, the components of the arm experience quite some play relative to each other. This could have been fixed by using heavier components. However, heavier components wouldn't benefit the player that is wearing the arm and it could be a problem budget-wise as well.

Shooting mechanism with magnets

Goal

The goal of this experiment is to find the relationship between the applied voltage over an electromagnet and the velocity of the billiard ball. The ball gets this velocity by the repelling force between an electromagnet and a permanent magnet.

Theory

In this experiment there is made use of a permanent magnet and an electromagnet. The difference between a permanent magnet and an electromagnet is that the magnetic field in the permanent magnet is permanent and the magnetic field in an electromagnet is generated by a current. A magnet consists of two poles: the north-pole and the south-pole. The north-pole attracts the south pole and vice versa. When the north-poles of two magnets are facing each other, the magnets will repel each other.

The relationship of the force

F in N between two magnets is:

$$F = \mu_0 \frac{M_1 M_2}{4\pi r^2} \quad (1)$$

Where μ_0 is the vacuum permeability is $4\pi \times 10^{-7}$ H/m, $M_{1,2}$ is the magnetic pole strength in Am and r is the distance between the magnets in m.

For electromagnets the magnetic pole strength is given by:

$$M = \frac{NIA_E}{L_E} \quad (2)$$

Where N is the number of windings of the coil of the electromagnet (unitless), I is the current running through the electromagnet in A, A_E is the cross-sectional area of the electromagnet in m^2 and L_E is the flux path length in m.

The resistance R in Ω in the electromagnet is given by:

$$R = \frac{\rho L_w}{A_w} \quad (3)$$

Where ρ is the electrical resistivity of the wire of the coil in the electromagnet in Ωm, L_w is the length of the wire of the coil in the electromagnet in m and A_w is the cross-sectional area of the wire of the coil in the electromagnet in m^2.

The voltage U in V is given by Ohm's law:

$$U = IR \quad (4)$$

The Work done by the force W in J is given by:

$$W = \int_{r_0}^{r} F \; dr \quad (5)$$

The kinetic energy of the billiard ball E_k in J is given by:

$$E_k = \frac{1}{2} m_b {v_b}^2 \quad (6)$$

Where m_b is the mass of the billiard ball in kg and v_b is the velocity of the billiard ball in m/s.
The transfer of momentum between the permanent magnet and the billiard ball is given by:

$$m_b v_b = m_m v_m \quad (7)$$

Where m_m is the mass of the permanent magnet in kg and v_m is the velocity of the permanent magnet in m/s.

By substituting the formulas 1-7 in each other the following formula can be found:

$$v_b = \frac{1}{m_b} \sqrt{\frac{\mu_0 m_m M_2 N A_E A_w U}{2\pi L_E L_D \rho} \left(\frac{1}{r_0} - \frac{1}{r}\right)} \quad (8)$$

So, the relation between the velocity of the ball and the applied voltage is:

$$U \sim {v_b}^2 \quad (9)$$

Experimental setup

The experimental setup is depicted in figure 1. An electromagnet is connected to an adjustable power supply. To one side of the electromagnet a permanent magnet is placed. When current runs through the electromagnet, the electromagnet becomes magnetic. The permanent magnet is placed in such way that when the electromagnet is turned on, the magnets will repel each other. Over the electromagnet a voltmeter is connected. The permanent magnet is placed in hollow cylinder such that the permanent magnet can only move in one direction. At the end of this magnet, a billiard ball is placed. When the permanent magnet has reached the end of the cylinder, the permanent magnet will hit the billiard ball and the billiard ball will start to roll. The billiard ball will roll a certain fixed distance. The time the ball rolls over this distance is measured with a stopwatch.

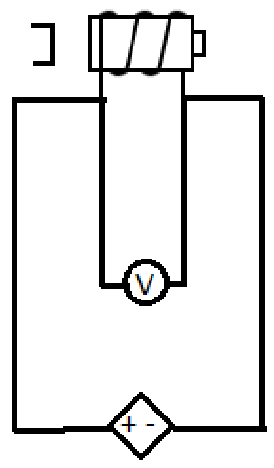

Figure 30 Schematic view of the setup of electric circuit used in this experiment

List of materials

- Electromagnet
- Permanent magnet
- Voltmeter
- Controlled voltage supply
- (Billiard) Ball
- Soft protecting material for the magnet
- Wires

Results

We were unable to do measurements for this test.

Conclusion

It is not possible with the used components to make a shooting mechanism using an electromagnet and a permanent magnet.

Discussion

The concept for the shooting mechanism with magnets did not work because it is not taken into account that the outside of the electromagnet was made out of metal that can be attracted by a magnet. So, the permanent magnet was attracted to the outside of the electromagnet. The magnetic field of the electromagnet was weaker than the magnetic field of the permanent magnet, so the electromagnet was not strong enough to repel the permanent magnet.

After this experiment we decided that the concept of the shooting mechanism with magnets should be abandoned, because we did not think that we could solve this problem by, for example making the electromagnet ourselves or buying another (stronger) electromagnet.

Test plan electric circuit

Goal

The goal of this test is to find out if the electric circuit we have built will work. The purpose of this circuit is that the acceleration of the movement of your arm can be converted to the time our motor is working.

Theory

In this test an acceleration will be measured. This acceleration is measured in g: the g-force. The g-force is, despite the name, another type of acceleration. This g is the gravitational acceleration. This value is not constant, and it depends on your place on earth and it varies on earth between 9.764 m/s^2 and 9.834 m/s^2. The conventional standard value for g is exactly 9.80665 m/s^2. This means when an acceleration of 2 g is measured, that the actual acceleration is 19.6133 m/s^2.

In this test an Arduino is used. An Arduino is a so-called microcontroller: a small computer dedicated to interaction with real world physical systems. In this circuit, the Arduino will read and process the data from the acceleration sensor and with this data the Arduino will control the servo and the transistor. A transistor is a switching device which regulates and amplify the electrical signal likes voltage or current. In this test the motor only has to be turned on and off, so the transistor will work as a switch in this circuit. Furthermore, a servo is used in this circuit. A servo, or servo motor, is a rotary motor that allows for a precise control in terms of angular position, acceleration and velocity. The servo used in this circuit can rotate 180 degrees.

Setup

In this test the acceleration of the arm must be converted to the time our motor is running. To do this, we make use of an Arduino. The acceleration sensor, the transistor and the servo are all connected to the Arduino. The Arduino is programmed that it can control the servo and the transistor, and the Arduino can read the values from the acceleration sensor and convert them to values for the transistor. The transistor will control the voltage over the motor. In this circuit the motor only has to be turned on and off, so the transistor in this circuit will work as a switch. The acceleration sensor must eventually be attached to an arm, but for this test the acceleration sensor can be moved in an easier way, for example by using your hands. The circuit will work in the following way: first, the acceleration sensor will measure an acceleration. These values go to the Arduino and the Arduino takes the maximal value for the acceleration. This value is converted into a time that the transistor will be turned on. The time that the transistor is turned on, the motor will run. After the time is up, the transistor (and therefore also the motor) will be turned off. At this exact moment the servo will be switched. After a given time the servo will switch back and the circuit will wait for another acceleration. Then this whole process will start again.

List of materials

- Acceleration sensor
- Arduino
- Motor
- Servo motor
- Transistor
- Wires
- Batteries

Test plan: shooting mechanism with spring

Goal

The goal of this experiment is to find the relation between the time the motor is running and the distance the spring is pressed. In other words, the goal of this experiment it to find the velocity of the pressing of the spring. Beside doing this experiment, we also looked at how the shooting mechanism as a whole works.

Theory

For this experiment a rotation motor[1] is used. This rotation motor has a rotation velocity of 1 rpm and the diameter of the rotation axis is 4.8 mm. Beside the motor, a spring is also present in the shooting mechanism. The force a spring can exert can easily be calculated by:

$$F = Cu \tag{1}$$

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[1] https://m.banggood.com/nl/DC-6V-1rpm-Reversible-High-Torque-Turbo-Worm-Geared-Motor-DC-motor-GW370-p-1055274.html?rmmds=search

Where F is the exerted force of the spring in N, C is the spring constant in N/m and u is the distance the spring is pressed in m. The spring used in the shooting mechanism[2] has a spring constant of 1.99 N/mm and the maximal distance the spring can be pressed is 66.4 mm. When these values are filled in in formula (1), the maximal force can be calculated which is 132 N. This should be enough according to our RPC's.

The spring is connected with the motor by a rope. The (absolute) velocity of the winding of the rope around the rotation axis of the motor can be calculated by:

$$v = \omega r \qquad (2)$$

Where v is the velocity in m/s, ω is the angular velocity in s^{-1} and r is the radius of the rotation in m. For the motor ω is 1 rpm which is approximately equal to $1.7*10^{-2}$ s^{-1} and r is equal to 4.8 mm or $4.8*10^{-3}$ m. When these values are filled in in formula (2), a velocity of $8*10^{-5}$ m/s can be calculated.

The time t in s the motor should run can be calculated by:

$$t = \frac{u}{v} \qquad (3)$$

The formulas (1) and (2) can substituted in formula (3) this gives as final result:

$$t = \frac{F}{C\omega r} \qquad (4)$$

In this experiment the relation between the time the motor is running, and the distance the spring is pressed is investigated.

Hypotheses

As result of this experiment a directional proportional relation between the time the motor is running, and the distance the spring is pressed can be expected with a velocity of about $8*10^{-5}$ m/s.

Experimental setup

In this experiment the distance the spring has pressed and the time it takes must be measured. The pressing of the spring is done by a rotation motor. The spring is connected with the motor by a rope. This rope is winded around a pulley. This pulley is connected to a gear which is connected to the motor by another gear attached to the rotation axis of the motor. The motor is powered by an adjustable power supply. The voltage and the current are kept constant. When the voltage is applied over the motor, the motor starts running and the spring will be pressed. The distance the spring is pressed is measured with a ruler and the time is measured with a stopwatch. The pressing of the spring is filmed with a camera of a mobile phone. This camera also films the stopwatch during the pressing. A schematic view of the experiment can be found in figure 1. A frame of the video can be found in figure 2.

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[2] http://www.industriele-veren.nl/online-shop/search?pid=22770

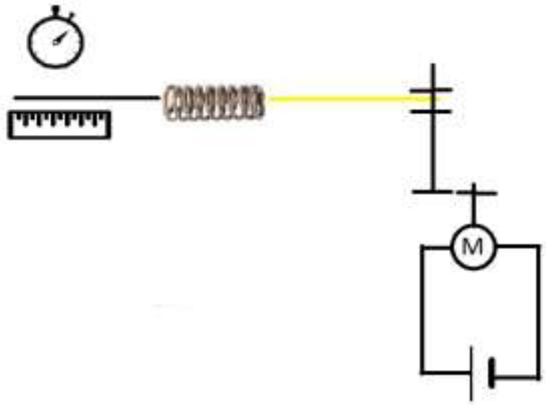

Figure 31 Schematic view of the setup

Figure 32 Frame of the video

List of materials

- Rotation motor
- Power supply
- Two gears
- Pulley
- Rope
- Spring
- Ruler
- Stopwatch
- Camera

Results

The results of this experiment are shown in the table below.

Table 1: The measured distance at each time

Time in s	Distance in m
0	61
5.28	60
8.68	57
10.59	55
13.04	54
15.95	53
21.19	51
27.18	50
31.42	48
35.47	47
41.45	45
45.48	43
50.36	42
55.42	40
60.64	38
65.42	36
70.49	35
75.47	33

80.52	32
84.98	30
91.26	28
95.55	26
100.39	25
105.38	23
110.46	21
115.4	20
117.98	20

These values are plotted with a linear fit. This Graph is shown in figure 3.

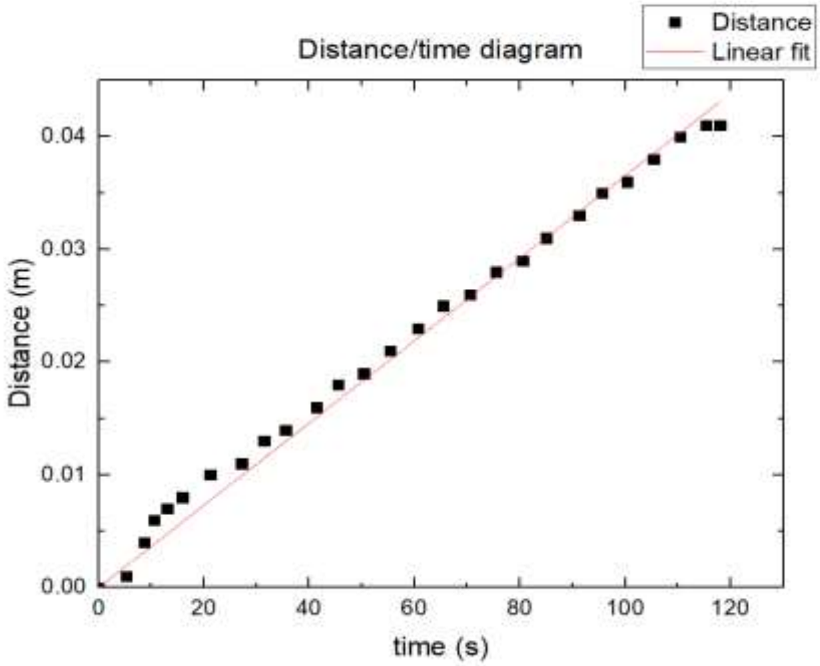

Figure 32 Plotted values with linear fit

The results of this linear fit are shown in the table below.

Table 2: Results of the linear fit

Equation	y = a + b*x		
Weight	No Weighting		
Residual Sum of Squares	3.81046E-5		
Pearson's r	0.99885		
Adj. R-Square	0.99761		
		Value	Standard Error
s	Intercept	0	--
	Slope	3.65276E-4	3.43965E-6

From this table it is visible that there is a directional proportional relation between the time and the distance where the slope (and thus the velocity) is (3.65±0.03) *10^{-4} m/s.

The velocity of the rotation can be calculated with formula (2). Given is that the angular velocity of the motor is 1 rpm, but this value is not accurate, so an uncertainty of 1 can be taken. The radius of the rotation axis is 4.8 mm with an uncertainty of 0.1 mm. So, the velocity is (8±8) $*10^{-4}$ m/s, which is very inaccurate

Conclusion

There is indeed a directional proportional relation between the time the motor is running, and the distance the spring is pressed. But the measured velocity is (3.65±0.03) $*10^{-4}$ m/s, which is not match the expected value.

Discussion

The concept of the shooting mechanism works pretty fine, better than the shooting mechanism with the magnets. The conclusion corresponds partially to the hypotheses. There is indeed a directional proportional relation between the time the motor is running, and the distance the spring is pressed, but the measured velocity does not correspond to the expected value. The expected value already has a very big uncertainty, but it is still possible that the value for the angular velocity is still very inaccurate, because the reviews say that the angular velocity of the motor is bigger. Beside the inaccurate angular velocity, the rope is winded around the pulley a few times. This means that the distance to the rotation axis increases during the experiment. This is not included in the calculations.

12 Design evaluation

In our opinion, we made a solid design. It is a creative and elegant solution for people without arms who want to play billiards or other cue sports. We tried to make a user-friendly solution for these people and we think that we succeeded. This is done by taking our RPC's in account as much as possible. For example, one of the preferences was that people with different lengths can use our design. This is done by making the design adjustable in height, so users of different length can use our design, and the arm can be tightened using bicycle straps. But the whole design process was not one without setbacks. The most problems were encountered at the design of the shooting mechanism and at the electronics. In our first concept for the shooting mechanism we made use of the repelling force between magnets. We already labeled this as a high risk in the risk management, so it was not a surprise that we did not succeed, but we dealt well with this drawback and we adapted the shooting mechanism in such way that it worked the way it should. Likewise, after a lot of work, we succeeded in getting the electronics working.

We are satisfied with the result of the design, but that does not mean that there is no room for improvement. For example, one of the most important things that can be improved is the time it takes before the user can hit the ball. One of the ways this problem can be solved is by making use of a more powerful motor, but that motor will be more expensive and will not fit in the budget. A second way to improve our design is to keep the rope (to press the string) constantly tense. In our design the rope must be tensed after the spring is released. Because the motor is not very powerful (and thus very slow) it takes a while before the rope is tensed again. Besides, the time that the motor should run to tense rope varies every time the spring is released. This can also be solved by keeping the rope constantly tense. Finally, the measured acceleration is not always the largest acceleration. This is due to that the acceleration sensor is constantly measuring. When the acceleration sensor measures an acceleration larger than a preset threshold, the measured acceleration is converted to the time the motor will run. After this measured acceleration, a higher acceleration can be measured but this acceleration will not be converted to a time. This problem can be solved by making changes in the code, for example measuring the acceleration in time intervals. The maximum acceleration from this interval (if it is larger than the threshold) will be converted to the time the motor will run.

Although our design can be improved in a lot of ways, we think that we can be proud on our final design. Our design is very creative and complicated, but it works the way it should work.