Engineering Strategies and Practice

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Conceptual Design Specifications

Team #	3	Date	March 19, 2019

Project Title	Measuring the Split Times of Curling Stones
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Executive Summary

Jason Chang, the skip for the Men's and Mixed Hong Kong International Curling Teams, has requested a design that will measure the split times of curling stones. In curling, the time it takes the stone to travel from one point of interest to another is called a split time. These measurements are used to make real time decisions about the sweeping strategy of a shot. Current solutions are too costly to be accessible to all members, especially if the team does not practice together. As outlined in this report, our team has developed requirements for this project as well as presented possible design alternatives. We have established steps to be taken to implement the proposed conceptual design, which will measure the split time of curling stones, as an alternative to stopwatches and existing costly systems.

Mr. Chang has outlined three split times of interest: back line to tee line, back line to hog line, and hog line to hog line. The first two times are used to compare the actual split time to the desired split time of the shot to adjust the sweeping strategy. The latter time is used by curlers to get a sense of the weight of the shot just thrown. Times are used during and after each shot to develop muscle memory for different weighted shots.

From information provided by the client and additional research, the team determined that the design will perform two primary functions: measuring the time taken for a curling stone two travel between two points of interest, and communicating that time to the user. Since our client's team practices separately, our design should maximize portability and require few people to operate it. As the current solutions are beyond the client's budget, a major goal of this project is to minimize the design's cost. Moreover, the ways in which the design communicates the data to the user will be a focus for the team.

The team has developed constraints on the proposed solution through research and from the client's knowledge of curling. This includes ensuring that the design will not impede the motion of curling stones, will not damage the curling ice in any way, and will not be fixed in place. Considerations have also been made to account for the environment where the design will operate. Proposed designs will be operable in curling facilities around the world, as curling facilities have very similar environmental conditions. Additionally, since the client and his team share the curling facilities while they practice, the perspectives of others within the facility are considered.

After establishing all requirements relevant to the project, the team proceeded with the Conceptual design phase, in which design ideas were generated using multiple brainstorming techniques, and assessed based on the Project Requirements. Of around 15 ideas generated, three designs that best conformed to the Project Requirements were selected. RadiCurl uses RFID technology, CurlourVision uses computer vision software, while PhotonRock uses lasers and photoreceptors to detect the curling stone. The three ideas were evaluated against the objectives of the project, primarily focusing on the accuracy, responsiveness, and affordability of each design. The team has proposed the PhotonRock design to the client. It is affordable, portable, provides the same accuracy as a stopwatch, and is theoretically more responsive than a human using a stopwatch. A testing method has been developed to confirm this quantitatively.

We will discuss the alternatives developed by the team with the client, and determine if the client would like to proceed with our proposed design. We will then move towards further testing to measure responsiveness and other specifications of the design before full implementation.

1.0 Introduction

The client for the project, Jason Chang, is a member of the Hong Kong national curling team, comprised of four members, the standard for most teams [1]. Curling involves two teams sliding granite stones down a sheet of ice towards the circular target at the opposite end, called the house [2]. The objective is for the team to land their curling stones closest to the centre of the house, called the button [2]. Mr. Chang has requested that the team design a device to measure the time taken for a curling stone to travel between two points on the ice. In curling, this type of time measurement is called a split time. [3] Figure 1 shows a standard curling rink, and labels all points of interest from which split times can be measured. These points include back line to tee line, back line to hog line, and hog line to hog line. All split time measurements allow curlers to know how hard they've thrown the stone, and how far it will go [3]. This document will define the problem presented by the client, and outline all relevant project requirements, conditions, and stakeholders associated with the project.

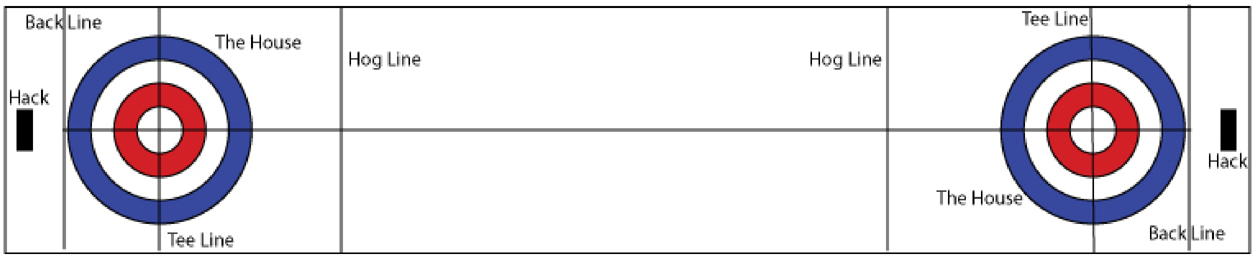

Figure 1. Points of interest on curling ice [4].

2.0 Problem Statement

Three types of split times are of interest to the client; from the back line to the hog line, the backline to the T-line, and between opposite hog lines. Current technologies that measure split times are too expensive to be accessible to all team members [6][7] (Appendix C). The client's team rarely practices together, as they live in different locations [5], meaning the cost of the design should be low enough to provide a separate device for each member to use individually in their respective practice facility. Stopwatches are an affordable method of measuring split times, however, they require at least one other person to be on the ice, and their accuracy depends on the reaction time and location of the person operating the stopwatch [5][8] (Appendix F). After meeting with the client and researching existing solutions to the presented problem the team has identified the gap as being a device that is compact, low-cost, and accomplishes the same task as existing technologies. The team has scoped the project to measuring the time it takes the curling stone to move between two locations and communicate that information to the user.

3.0 Detailed Requirements

The following sections outline all requirements applicable to a design used to measure time, specifically in the setting of a curling facility. Functions, objectives and constraints were generated through discussion with the client, research on characteristics of curling facilities (see Section 4.0), and techniques used in practice. These requirements will help guide the team during the design process.

3.1 Functions

The following table lists the functions performed by a device when measuring split times of a stone between locations. Using the Functional Basis tool, the team extracted secondary functions by determining what functions will result in a device that measures split times and communicates the result. (Appendix A)

Table 1: Functions of the Design

Primary Functions	Secondary Functions
Measure the time taken for a curling stone to move between two points.	● Detect when stone reaches start point ● Begin measuring time ● Detect when stone reaches end point ● Stop measuring time
Communicate information to user.	● Store data recorded ● Transform data into understandable information ● Output data to user

3.2 Objectives

The objectives of the timing device are provided in Table 2 to help evaluate potential designs. Objectives of the project were generated by considering desirable characteristics for timing devices used by curlers during practice and before competitions. Table 2 outlines the goals and corresponding metrics in descending order of importance (Appendix B).

The design should be:

Table 2: Project Objectives

Objective	Measure of Success	Objective Goal
Accurate	Error of timing mechanism	Accurate time reading to 1/100ths second (s) [6]
Responsive	Reaction time of design	Starts/Stops time within 1/100th of a second of stone detection [6]
Affordable	Cost of design	$500 cost for the entire team [5]

Portable	Dimensions and weight of the design	Smaller than 13.97 cm x 5.72 cm x 7.62 cm and less than 8 ounces [6] (Appendix C)
Quick to set up	Time taken to set up the device	2 minutes or less [5]
Suitable for independent use	Number of people required to use	One person [5]
External network independent	External networks required for use	Does not require Internet or Bluetooth networks [9]

3.3 Constraints
The constraints of the project explore the restrictions established by the team to ensure that the timing device can properly perform the established functions, measuring a split time, and communicating it. Table 3 lists these constraints, associated limits, and their metrics.
The design shall:

Table 3: Project Constraints

Constraint	Metric	Constraint Limit
Not physically alter ice structure [5]	How much the physical structure of ice in facility is altered on a macroscopic scale.	Will not contain sharp edges. Does not increase temperature of ice by more than 5℃ [12][13] [20] (Appendix D) This will prevent ice from being damaged or melted
Not affect motion of the stone [5]	Yes/no test	Does not affect, to avoid impeding gameplay
Affordable price [5]	Cost of design (Appendix E)	$1000 or less for entire team, per client budget [5]
Minimize set-up time [5]	Set-up time of device	Fewer than ten minutes, as practice times are usually one hour [5]
Not fixed in place [5]	Yes/no test	Design moves freely, so device can be used in multiple facilities, as stipulated by client
Not require electrical outlet [8]	Yes/no test	No electrical outlet required, ensure that the device can operate on any ice surface, regardless of outlet availability.

Be accurate to five hundredths of a second [8] [10]	Error of timing mechanism	Minimum accuracy to 0.05s, to ensure device is as accurate as a stopwatch

4.0 Service Environment

The design will operate in curling rinks. No particular curling venues are considered when describing the context, as the design may operate in curling facilities across continents [5]. Standard conditions in curling facilities are considered when describing where the design will operate.

4.1 Physical Environment
Environmental conditions are maintained within curling venues, and control measures are carried out by ice technicians to prevent variance [11] . Thus, stable environmental conditions can be expected.

- Standard conditions of the curling rink:
    - Ice surface temperature: -4.5℃ to -5℃ [12]
    - Relative humidity at 1.5m: ~40% [12]
    - Air temperature at 1.5m: ~8℃ [12]
- Building facilities:
    - An average of 350 lux lighting is recommended per curling sheet [13] .
- Curling stones:
    - Travel at an average speed of 2 m/s after release during game play [14] .
    - Weigh between 38 Lbs - 44 Lbs [1].

4.2 Virtual Environment
The availability of adequate signal within curling facilities is an important factor in addressing the design's data transmission mechanism.

- Limited signal transmission due to wireless interference from the refrigeration system in curling buildings [9][16][17].

4.3 Living Things
The presence of other players in the curling rink increases the likelihood of collisions with the design.

- Generally a maximum of eight people are allowed on a curling sheet, which has dimensions that vary from 146-150 feet by 14.2-15.7 feet [17] [18].

5.0. Stakeholders

This section describes how different people and organizations might impact or be impacted by the use of new timing methods in curling facilities. Since the design will be used by curlers, different groups that interact with the sport are considered. The effects were evaluated based on research and information provided by the client.

Table 4: Project Stakeholders

Stakeholders	Impact

Curlers sharing the space	The practice facility is shared with other players and users [10] , and a customized timing device could cause distractions.
Provincial/Territorial curling associations World Curling Federation Hong Kong curling association [20]	The use of the device may improve gameplay and increase competition, attracting players and fans. [19]
Owners of curling facilities	Some facilities may be incompatible with the device, causing its disallowment by facility owners.
Ice making/maintaining technicians	The device may cause changes to the ice quality which is maintained by the ice technicians. [21]
Coaches [22]	The use of this device by nationally qualified coaches may cause changes in training techniques. With more available data, coaches may develop new training methods.

6.0 Alternative Designs

Multiple brainstorming techniques were utilised by the team when generating ideas for the curling split timer design. When brainstorming, any ideas that failed to meet a constraint were immediately discarded, and decomposing the functions helped in generating different design alternatives. The RadiCurl design was generated through the analogy method, with Radio Frequency Identification (RFID) technologies used in retail security systems. The 'Combine' aspect of SCAMPER was used to developing CurlourVision, which combines OpenCV (library of computer vision programming functions) and Playstation cameras in a colour sensor. By benchmarking existing technologies such as "RockHawk" [6], the Photon Rock was generated.

Arduino UNO is used in all three designs to measure time. CurlourVision outputs data through a computer screen, while the other two designs use a Liquid Crystal Display (LCD) connected to the Arduino. RadiCurl and Photon Rock utilize 433 Mhz wireless transmitters and receivers to communicate data between Arduino circuits. All three designs use Arduino's internal timing capabilities to compute the split time. Thus, the following designs outline three different mechanisms to detect when to start and end timing.

6.1 RadiCurl

RadiCurl uses RFID technology to detect a curling stone crossing a point of interest. Two reader modules set up Radio Frequency (RF) fields along designated points of interest on a curling sheet [28], and RFID tags are attached to curling stones. When curling stones cross each point of interest, the RFID tags respond to the RF field by sending a signal to the reader module to start or end timing [29], accomplishing the first primary function. The split time measured will be displayed on a LCD screen, performing the second primary function.

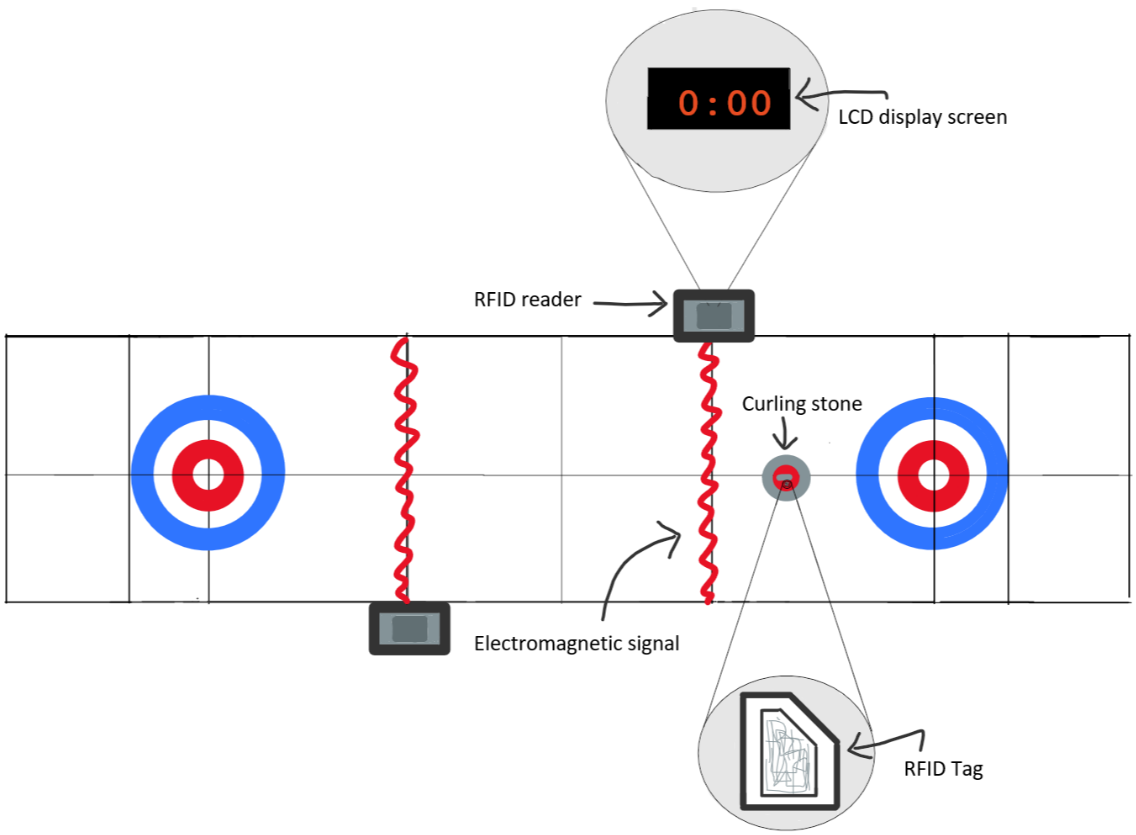

Figure 2. Setup for RadiCurl

Table 5: RadiCurl in comparison with objectives

Objective	Performance of RadiCurl
Accurate	Arduino measures time in milliseconds [30].
Responsive	RFID tag receiving and backscattering a signal occurs within milliseconds [31][32].
Affordable	2 x reader module: 2 x $300.00 = $600.00 [32] 2 x Arduino Uno: 2 x $22.00 = $44.00 [33] LCD Screen = $17.66 [34] 10 passive UHF RFID tags = $1.13 [35] Total = $662.79
Portable	Size of RFID tags vary from 1 in x 1 in, to 4 in x 4 in, typically weigh < 1g [36][37]. Battery powered RFID reader module weighs 7g [38], Arduino UNO weighs 25g [39], LCD screen weighs 63.5g [40].

Easy to set up	1. Attach RFID tag onto curling stone 2. Place RFID reader on one end of each point of interest
Suitable for independent use	One person is sufficient to set-up the system. Design operates independently.
Network independent	Communication between RFID readers and RFID tags done by exchange of electromagnetic waves [28].

6.2 CurlourVision

CurlourVision utilizes computer vision software, OpenCV [41], to track the specific colour code of the curling stone. Using a camera, it tracks when the stone crosses each point of interest, and measures the time elapsed. Two cameras will be placed on the sides of the curling sheet by the tee and hog lines, each attached to an Arduino that tracks time. This data will be transferred to a laptop screen, fulfilling the second primary function.

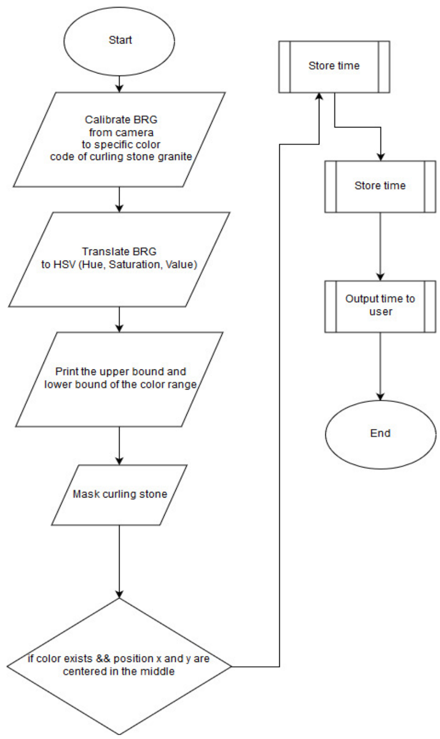

Figure 3. How CurlourVision works using OpenCV [42]

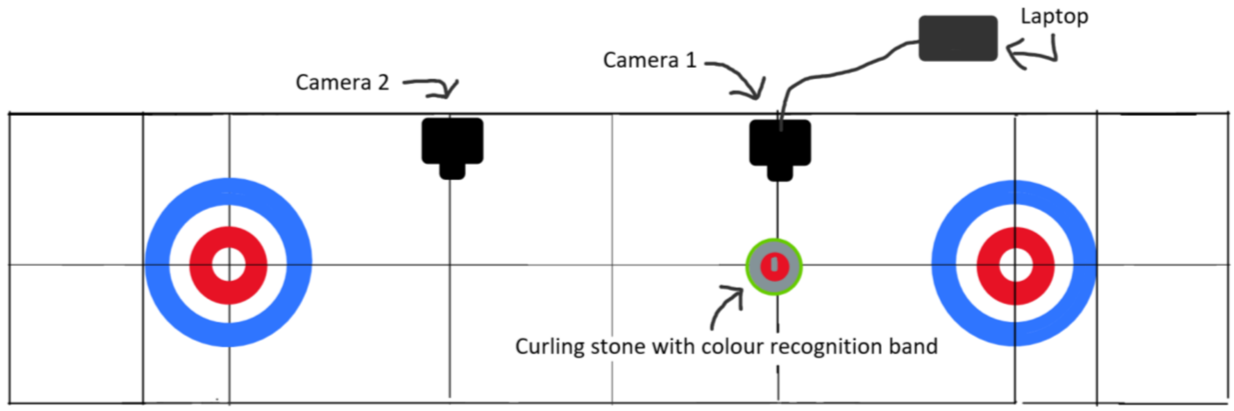

Figure 4. Setup for CurlourVision

Table 6: CurlourVision in comparison with objectives

Objective	Performance of Design (specify name)
Accurate	Accurate to 0.01s using a webcam of 100 frames per second. The PlayStation Eye records up to 120 fps with 320 x 420 resolution.[43]
Responsive	A mechanism will be used to determine the accuracy and speed of OpenCV [44]
Affordable	Playstation Eye < $30 CAN [45]. OpenCV is free.
Portable	PlayStation Eye camera is 84 x 67 x 57mm [43]. Analysis software requires a computer and connective equipment.
Easy to set up	1. Install software on laptop 2. Position cameras at points of interest
Suitable for independent use	One person operates the software, while all calculations and sensing are automated.
Network independent	Cameras attach to computer via USB. [42]

6.3 Design 3 - PhotonRock

This design relies on laser technology. PhotonRock uses laser emitters [46] and photoreceptors [47] to detect the curling stone passing each point of interest. Lasers are aligned facing the photoreceptor. When a curling stone passes through the interest point, the sensor detects the absence of light and the process described in Figure 5 takes place [48]. This achieves the first primary function of the design. The count will be computed by the main circuit and output via an LCD display [34], performing the second function.

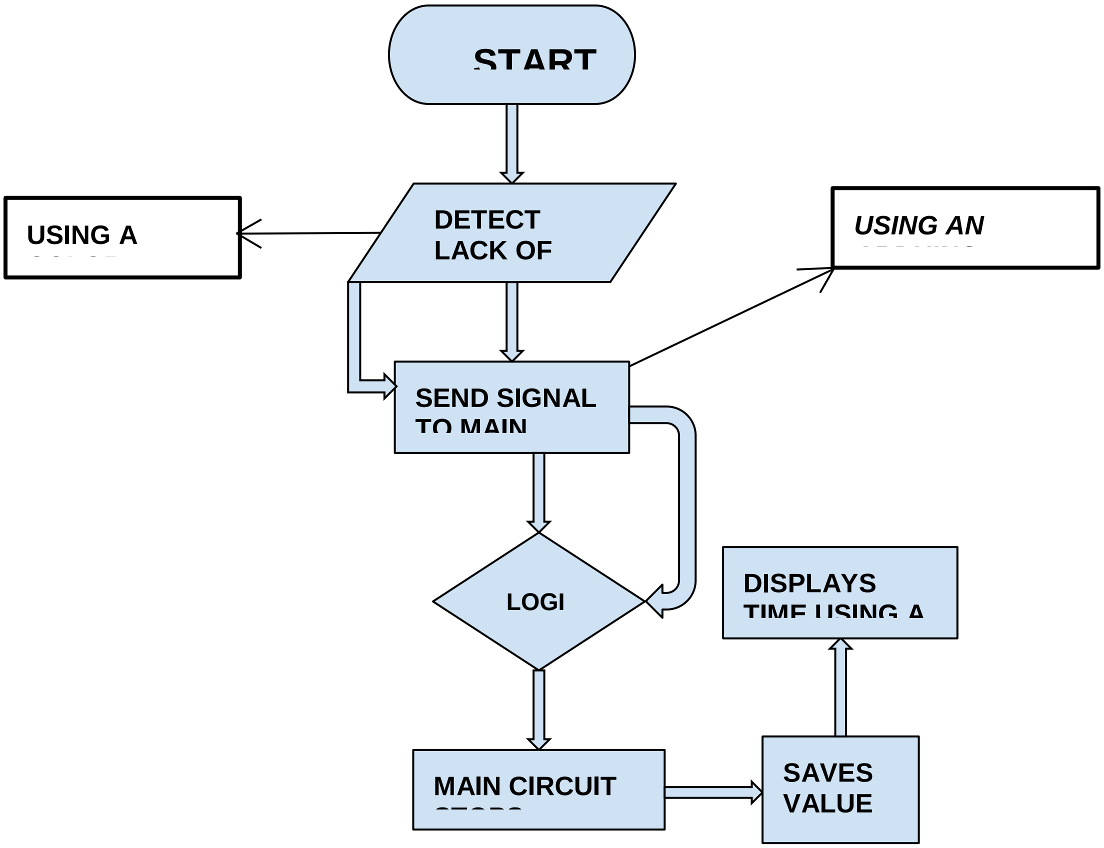

Figure 5. PhotonRock Flowchart

Table 7: Photon Rock in comparison with objectives

Objective	Performance of Multi-Laser Network
Accurate	Arduino measures time in milliseconds [30]
Responsive	Radio waves travel at the speed of light, further testing is required [49]
Affordable	2 x Laser = 2 x $21.62 = $43.24 [46] 2 x Color Sensor = 2 x $11.28 = $22.56 [47] 2 x Arduino Uno: 2 x $22.00 = $44.00 [30] 2 x Arduino Uno Case: 2 x $9.90 = $19.80 [50] LCD Screen = $17.66 [34] 433 MHz Wireless Transmitter Receiver Kit = $2.50 [48] Total cost= $167.42
Portable	68.6mm (length) x 53.4mm (width) x 170mm (height of antenna) ~110 g [30][34][50][51]
Easy to set up	1. Place circuits at point of interest 2. Turn on each circuit
Suitable for independent use	No manual operation after setup

Network independent	Uses 433 MHz radio waves [51] [52]

7.0 Proposed Conceptual Design

PhotonRock

PhotonRock was selected as the proposed conceptual design, because it best meets the client's needs. It fulfills all the functions and objectives for an affordable, accurate device that measures split times. PhotonRock was chosen because it was the most affordable for the client, and is very responsive and portable for the client's needs. When considering design alternatives, a weighted decision matrix was used to compare designs in terms of how they met project objectives [Appendix I]. From this method, PhotonRock scored the highest because it outperformed the other designs in price, accuracy, responsiveness and portability.

The PhotonRock system consists of small and inexpensive components including Arduino circuits, small laser pointers and photoreceptors [Table 7]. The laser detection process is near instantaneous as the laser beam travels at the speed of light. Transmitting of data within the system is done by an Arduino circuit, which was chosen due to its affordability and ease of implementation. The main circuit utilizes Arduino's built in counter and implements an LCD display. The internal circuit timer measures the time within milliseconds [table 7], ensuring accurate measurements. The data is communicated to the user using an LCD screen connected to the main Arduino circuit, making the information easily accessible. Based on this analysis and research conducted by the team, PhotonRock was confirmed to be the optimal design. The way that PhotonRock functions is described in Figure 5 and illustrated in Figure 6.

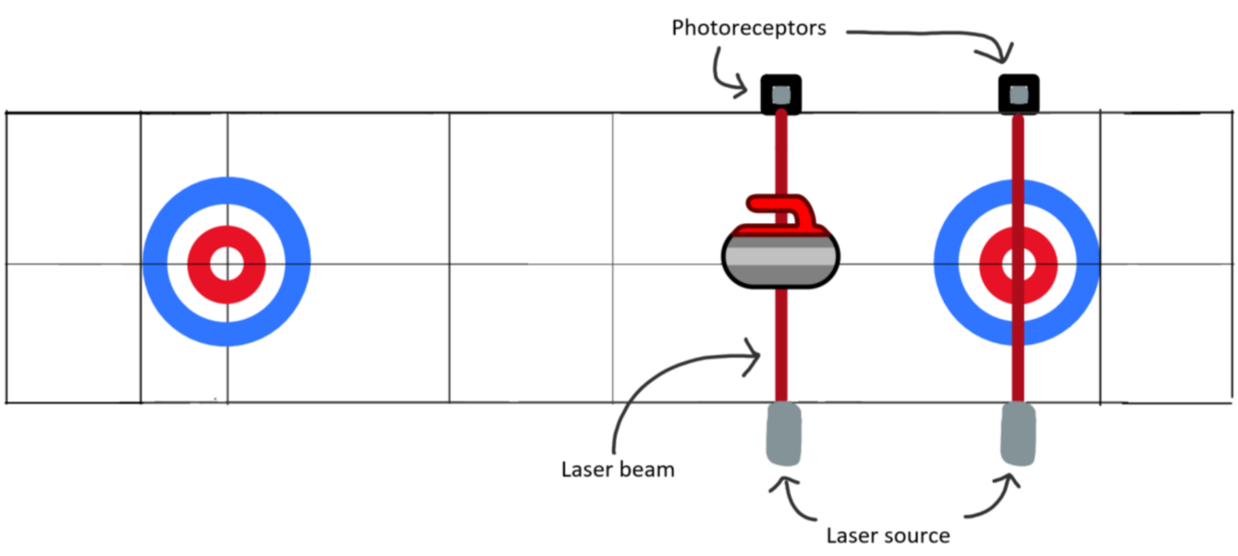

Figure 6. Setup for PhotonRock

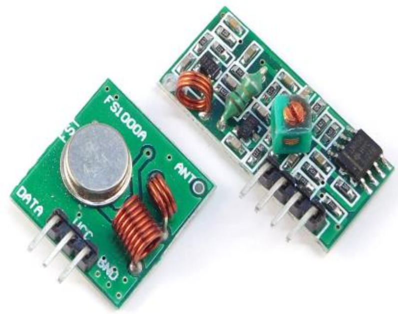

Figure 7. Transmitter & Receiver [48] *Figure 8. LCD Screen [34]* *Figure 9. Arduino Uno [30]*

8.0 Measure of Success

The team aimed to develop a solution that is more accurate than a human using a stopwatch to measure split times. Furthermore, we established that the reaction time of the design should be faster than a human. The measured reaction time will prove to the client that PhotonRock is worth implementing.

After developing a prototype of the design, PhotonRock's reaction time will be tested through video analysis. Figure 8.1 shows the setup of the test, where one photoreceptor and laser pair will be tested. The goal is to measure how long it takes the device to start its internal timer after the curling stone passes the point of interest. This is referred to as the device's "reaction time."

A camera with a frame rate of 100 fps will provide a test accuracy to 0.01 seconds. An indicator light will illuminate when the timing has started, and will be attached to the device so this instant in time can be identified with video analysis. The camera will be set up across from the device to record the operation as the object passes by.

The team will perform this test five times. The footage will then be analysed using "Tracker Video Analysis and Modelling Tool." software. Figure 8.2 shows an example of this software. Using Tracker, the difference in time between the object passing and the device beginning its time measurement can be measured. After averaging the data, the reaction time will be compared to a human's minimum reaction time of 0.05 seconds [10]. We can then prove if our client should implement this design.

As outlined in Section 6.3, the remaining objectives will also be evaluated. Accuracy and portability can be obtained from manufacturer specifications, while exact setup time can be tested. See 6.3 for more details.

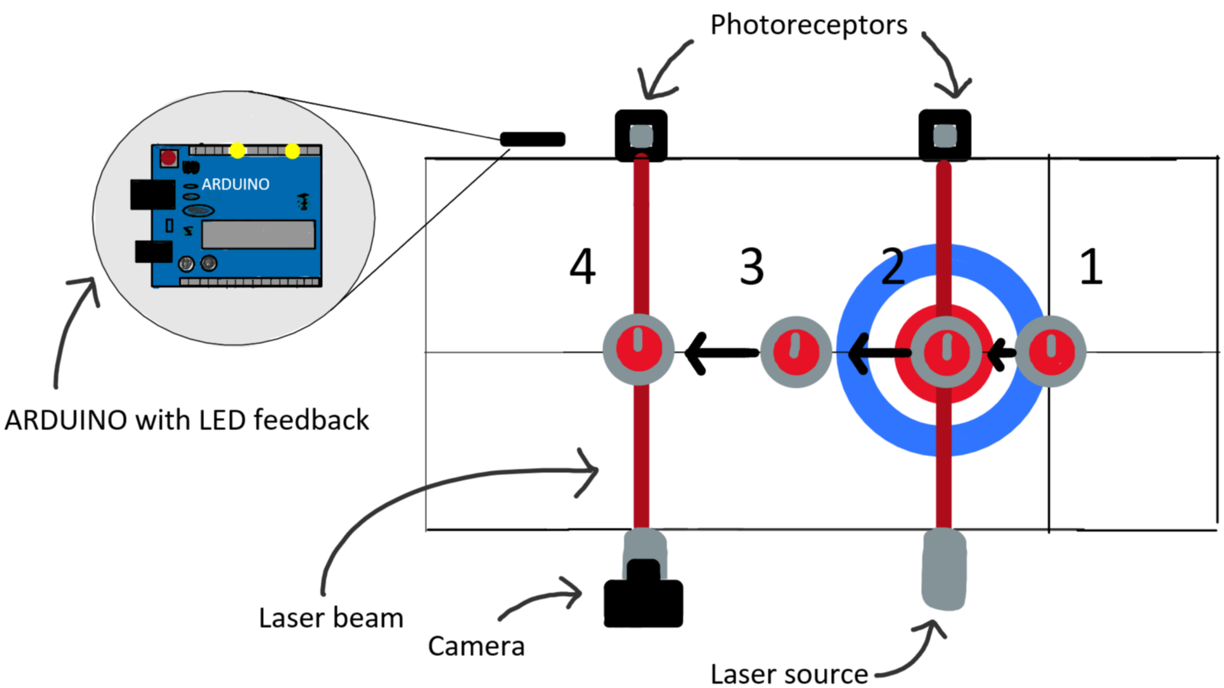

Figure 8.1 Setup of system to test PhotonRock's reaction time

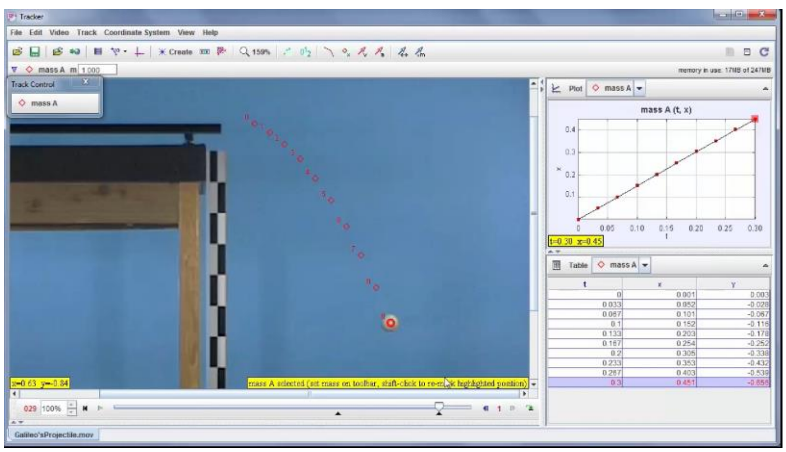

Figure 8.2 Tracker Video Analysis Software

9.0 Conclusion

In this document, the team analyzed key requirements for an inexpensive design that can accurately measure split times. The design should measure the time taken for a curling stone to move between two points, and communicate this information to the user quickly. Following discussions with the client and additional research, ensuring the design does not change the temperature or damage the ice, as well as minimizing cost constrain potential solutions. Stakeholders related to the project were considered as people and entities impacted by the implementation of the design. In the conceptual design phase the team used the established requirements to propose three designs to measure the split time of a curling stone, and assessed how these designs met the objectives. The team then proposed Photon Rock for further implementation, and was explored in depth in Proposed Conceptual Design. Next steps in this project include prototyping the design and further testing its performance meeting the objectives.

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Appendices
The Appendices contain resources and research relevant to the project, but which are not vital. Included in the Appendices are tools used by the team to generate Functions and Objectives, such as a Functional Basis and Pairwise Comparison of Objectives. Additionally, background research used to benchmark existing technologies is included.

Appendix A.

Table 5: Functional basis

Change	**Flows (Mass, Energy, Information)**
Detect	Mass
Generate	Information
Store	Information
Transmit	Information

Appendix B
A pairwise comparison was used to order the objectives from least to most important. Table 5 shows the process.
Table 6: Pairwise Comparison for ordering of Objectives

	Accurate measurement	Easy to set up	Portable	Durable	Independent use	Network independent	Total
Accurate	---	1	1	1	1	1	5
Easy to set up	0	---	0	0	1	1	2
Portable	0	1	---	1	1	1	4
Durable	0	1	0	---	1	1	3
Independent use	0	0	0	0	---	1	1

Network independent	0	0	0	0	0	---	0

Appendix C
Rock Hawk Curling Timer data [6]
Dimensions (cm): 13.97 (height) x 5.72 (width) x 7.62 (depth)
Weight of sensor box: 7.8 ounces
Weight of laser box: 8 ounces
Batteries, each box: 2 AA batteries
Battery life: > 100 hours
Range of sensor box: > 45 meters
Rock speed accuracy: 1/100ths meters per second (m/s)
Beam-to-beam accuracy: 1/100ths second (s)

Chronocurl Curling Split Timer [7]
Compatible with iOS and Android operating systems
Set up time is under a minute
Total price for one measuring device: $295.00

Table 7: Price Range for Rock Hawk Curling Timer and Associated Features

	1 Beam	2 Beams	3 Beams
Timing Beam	$349.00	$698.00	$1047.00
Rock Hawk App	$24.99	$24.99	$24.99
Total	$373.99	$722.99	$1071.99
Carrying Case (optional)		$24.00	$49.00

Appendix D

Table 8: Ice and the effect heat has on it

Characteristic of Ice	Measurement
Amount of heat that heats 1 gram of ice by 1℃	2.027 Joules at -5℃ [21]
Temperature of ice	Between -4.5℃ and -5℃
Thickness of ice	3.8 - 5.1 cm [22]

Since the team does not want to cause any damage to the ice, the above data shows that there should be no more than 2.027J of energy produced by the device in order to not affect the thickness of the ice

Appendix E

The following prices for various curling equipment were acquired from Balance Plus - a large brand that sponsors the US curling team [23]

The price for various high end curling equipment:

- Shoes: $120 - $290 [25]
- Broom: $90 - $180 [26]
- Stopwatch: $30 [5]

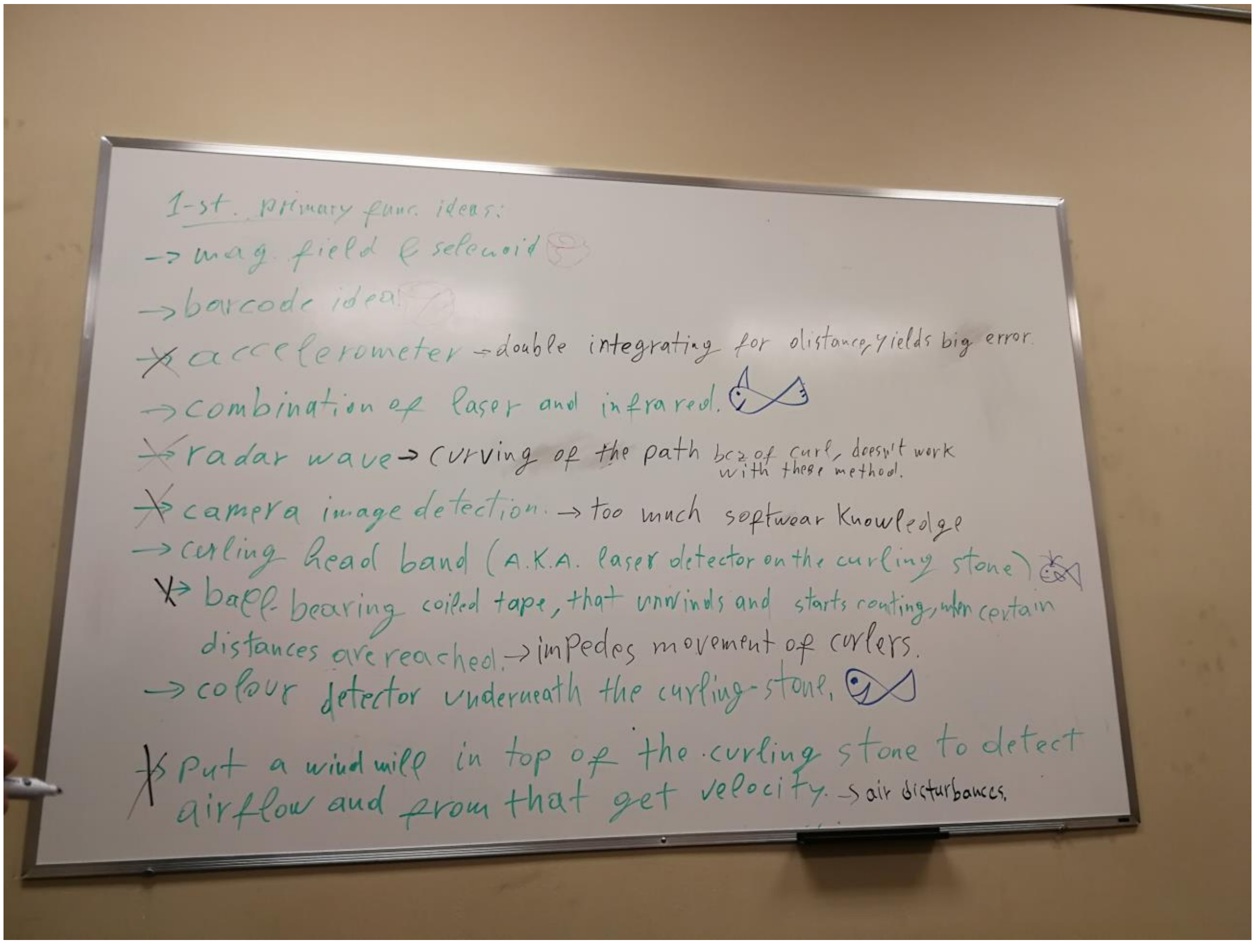
Leading up to an average total of about $100 per athlete. There are five members of the team therefore there must be a cost of under $500 total to compare to other costs of curling

Appendix F [7][8]

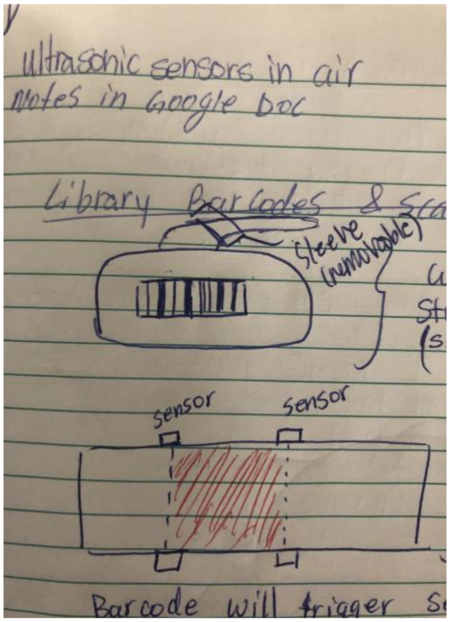
In curling, accuracy is very important, as with certain shots, measuring a split time that is 0.1 seconds off from the actual time can lead to the stone ending up six feet away from its target (2). The fastest reaction time that a person using a stopwatch can provide is 0.05 seconds (2), meaning that for some shots, measuring the split time with a stopwatch can lead to the shot being three feet off target.

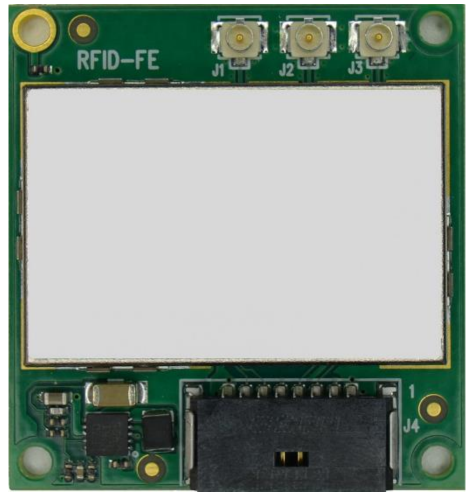
Appendix G

Idea generation



Appendix H





Appendix I
Ranking and weight of Objectives, and Weighted Decision Matrix used in comparing Alternative Designs in the Conceptual Design Phase. The weighted values given to the objectives on the decision matrix were determined by the rank of importance given by the client.

Objective *(Weight of Objective)*	**RadiCurl**	**CurlourVision**	**PhotonRock**
Accurate *(20%)*	75%	80%	75%
Responsive *(18%)*	85%	60%	90%
Affordable *(15%)*	5%	90%	95%
Portable *(12%)*	90%	90%	70%
Durable *(11%)*	40%	70%	85%
Easy to set up *(10%)*	80%	70%	95%
Suitable for independent use *(9%)*	85%	70%	30%
Network independent *(5%)*	100%	70%	95%
Total Score	67.4%	75.6%	80.15%