Title	Through View : a visual assistance system for reverse driving using retroreflective projection technology
Sub Title	
Author	Chang, Shian Wei(Inami, Masahiko) 稲見, 昌彦
Publisher	慶應義塾大学大学院メディアデザイン研究科
Publication year	2012
Jtitle	
JaLC DOI	
Abstract	This thesis describes the design and evaluation of ThroughView, an in-vehicle visual assistance system, that allows the driver to "see through" the backseat and observe the rear blind zone. Devices for indirect vision such as rearview mirrors do not o er a complete rearward view. Camera systems show a wide view but on a small display and tend to be panoramically distorted. An augmented vision system, known as the transparent cockpit, uses retrore ective projection technology to let drivers virtually see through the car interior, but has not been designed as an aid for driving. Based on the transparent cockpit, the proposed system in this thesis combines the directly-observed view with a camera image of the rear blind zone, thereby expands the rearward view that drivers see when they physically look back. The nal design is a compact, attachable device that can be secured onto the back of the driver seat. Evaluation of the system involving reverse driving tasks shows ThroughView to be e ective as a visual aid in backing maneuvres and is intuitive to use.
Notes	修士学位論文. 2012年度メディアデザイン学 第206号
Genre	Thesis or Dissertation
URL	https://koara.lib.keio.ac.jp/xoonips/modules/xoonips/detail.php?koara_id=KO40001001-00002012-0206

Master's Thesis
Academic Year 2012

ThroughView
A Visual Assistance System for Reverse Driving Using Retroreflective Projection Technology

Graduate School of Media Design
Keio University

Chang Shian Wei

ThroughView

A Visual Assistance System for Reverse Driving Using Retroreflective Projection Technology

by

Chang Shian Wei

B.A.(Hon), National University of Singapore, Singapore, 2004

Submitted to the Graduate School of Media Design
in partial fulfillment of the requirements for the degree of

MASTER OF MEDIA DESIGN

at the

KEIO UNIVERSITY

Academic Year 2012

Certified by . . . .
Professor Masahiko Inami
Professor, Graduate School of Media Design
Thesis Supervisor

Certified by . . . .
Professor Naohisa Ohta
Professor, Graduate School of Media Design
Thesis Co-Supervisor

Accepted by . . . .
Professor Masa Inakage
Professor and Dean, Graduate School of Media Design

(Signature) ______________________________

Graduate School of Media Design

Keio University
Hiyoshi, Yokohama, Japan

Date ______________________________

Master's Thesis
Academic Year 2012

ThroughView
A Visual Assistance System for Reverse Driving Using Retroreflective Projection Technology

Abstract

This thesis describes the design and evaluation of ThroughView, an in-vehicle visual assistance system, that allows the driver to "see through" the backseat and observe the rear blind zone. Devices for indirect vision such as rearview mirrors do not offer a complete rearward view. Camera systems show a wide view but on a small display and tend to be panoramically distorted. An augmented vision system, known as the transparent cockpit, uses retroreflective projection technology to let drivers virtually see through the car interior, but has not been designed as an aid for driving. Based on the transparent cockpit, the proposed system in this thesis combines the directly-observed view with a camera image of the rear blind zone, thereby expands the rearward view that drivers see when they physically look back. The final design is a compact, attachable device that can be secured onto the back of the driver seat. Evaluation of the system involving reverse driving tasks shows ThroughView to be effective as a visual aid in backing maneuvres and is intuitive to use.

Keywords: augmented reality, blind spot information system, visual assistance system, retroreflective projection technology, reverse driving

Thesis Advisor: Professor Masahiko Inami
Thesis Co-Advisor: Professor Naohisa Ohta

Graduate School of Media Design
Keio University

Chang Shian Wei

Table of Contents

Appendices

List of Tables

List of Figures

Acknowledgements

This thesis would not have been possible without the guidance and support of Professor Masahiko Inami. I would like to thank Professor Naohisa Ohta for his invaluable feedback during the mid-term presentation. I would also like to thank the team members of this project, Naoya Koizumi and Yuji Uema, for their technical expertise in optics and programming, as well as for their active cooperation. The use of Latex to write this thesis was made possible through the assistance of Charith Fernando. Last, but not least, I would like to thank all my family and friends for their unconditional love and endearing support, especially Zhang Wenjing.

Chapter 1

Introduction

1.1 Background

The modern-day car affords a quiet, comfortable and safe interior to ride in but, at the same time, shuts out the sensory signals from the environment. As a result, a driver may not be completely aware of the surrounding during a maneuvre. Visual blind spots are of safety concern. In particular, the area behind the vehicle, known as the rear blind zone, is not easily observable (2.1.1). Young children, especially, may not be seen due to their short stature. Every year in the U.S., 228 people die from backover crashes, of which is overrepresented by children under 5 years old[4] (2.1).

There are many devices that a driver can rely on to obtain information on the area behind the vehicle. Rearview mirrors (2.1.1) give reflected images of the rear surrounding that is only visible from both sides of the vehicle and from the rear window. "Cross-view" and backing mirrors provide views of the rear blind zone, but reflected images tend to be small and distorted . Rearview camera systems (2.1.1) offer a wide view of the rear blind zone but the image tends to be panoramically distorted and is displayed on a small screen. Sensor-based warning systems (2.1.3) provide audio or visual warning signals to indicate the presence of obstacles behind the vehicle but exhibits inconsistent detection.

The use of these devices presents a number of human factors issues. With the mirrors, visual information is fragmented and requires constant switching of attention in order to obtain a complete view of the rear (2.1.2). In the case of camera systems, placing attention on the screen in the car means that the driver is unable to physically observe the surroundings of the vehicle. Image distortion in both convex mirrors and camera systems tend to make it difficult to accurately perceive distances. Furthermore, drivers may suffer from poor visual-motor coordination when backing the car due to the mental rotation effect experienced as a result of using either devices. Lastly, the unreliable detection by sensor-based systems tends to be ignored as false warnings, which is dangerous.

In order to expand the driver's view of the rear surroundings, researchers have proposed a number of novel ways. Panoramic vision (2.2.1) is proposed as a way to capture a ultra-wide view using one or more omni-directional cameras and showing it on a head-mounted display or on multiple screens. Panoramic images, however, tend to be low in resolution and not ideal as visual displays. Bird's eye view vision (2.2.2) is another way of observing the surroundings through a virtual camera angle. The entire perimeter of the vehicle may be easily seen. However, the bird's eye view image is blended from a number of camera images, hence objects that lie in the blending zone may not be recognizable. The last way is by augmented vision (2.2.3), whereby the physical view is combined with an overlay of real-time visual information. One solution uses a Head-Up Display to present visualizations of detected obstacles over the physical view. Another proposed system merges captured camera images with the physical view using retroreflective projection technology. However, it requires the driver to wear a Head-Mounted Projector which is not practical for use in actual driving tasks. Nevertheless, the transparent cockpit concept has the potential to address much of the human factors issues associated with the other devices of indirect vision (2.3), and should be further developed.

1.2 Research Aim

The goal of this thesis, therefore, is to design and evaluate a visual assistance system that allows the driver to "see through" the backseat and directly observe the rear blind zone. This system will expand the rearward view that a driver sees when he/she physically looks back. It will be based on the transparent cockpit concept[59], using retroreflective projection technology.

1.3 Overview

The proposed system, ThroughView, is an attachable device that can be installed into a vehicle without alteration to the interior. It consists of five components: 1) a camera, 2) a processor, 3) a projector, 4) a half-mirror display and 5) a retroreflective screen. The camera is mounted at the back of the vehicle to capture the rear view. The processor (laptop) is placed in the car to process the images so that they can be correctly displayed. The projector and half-mirror display are attached to the driver seat. The retroreflective screen covers the backseat.

When the vehicle is set on reverse, the system activates and displays an image of the rear environment onto the backseat. The driver may look back and observe both the physical and camera view at the same time, thereby see an expanded view of the rear surroundings.

ThroughView underwent three iterations of designing, prototyping, implementing and testing (3.2). Quick mockups were made and tested in the car interior in order to verify important parameters such as projection distance, angle of mirror and viewpoint. Working prototypes were then built and implemented into the car (3.4)(3.5)(3.7). The first two prototypes were evaluated internally by the team (3.6) and the third prototype, by a group of drivers (4.2). Evaluation of the system showed it to be useful for its purpose (4.3).

1.4 Roles and responsibilities

This thesis is part of a collaborative project. My role in the team is an industrial designer. I am responsible for the human factors research, product design, prototype and implementation of ThroughView.

Naoya Koizumi and Yuji Uema are the engineers of the team. Naoya Koizumi is responsible for developing the image processing program for ThroughView while Yuji Uema is involved in the optics of the system.

1.5 Organization of the Thesis

This thesis is divided into 5 chapters.

Chapter 1 has introduced the motivation and goal of my research. A general overview of the thesis is provided to give a clear idea of what has been achieved. The process, design of ThroughView, evaluation and outcome are briefly discussed. My role and responsibility in the project is also stated.

Chapter 2 covers in detail the research related to the reversing driving problem and the current solutions. Human factors issues surrounding the use of rearview mirrors, camera systems and sensor technologies are discussed. Academic research on in-vehicle vision technologies are also reviewed. Finally, the novelty of ThroughView is proposed based on the design and usability issues examined.

Chapter 3 details the design and implementation process of ThroughView. First, the concept, methodology and guidelines for design are given. Next, detailed descriptions of three prototypes are presented. This includes the design of the technical system, product design and method of calibration. The issues identified in an initial evaluation of the first two prototypes are used to inform the design of the third prototype.

Chapter 4 describes the evaluation of the third prototype system. The aim and methodology are first explained, followed by a detailed account of the test procedure. Results of the test, observation and feedback from participants are then presented.

Chapter 5 concludes with a discussion of the results and its implications for further design development and commercialization. Possible improvements to the system and future research topics are also proposed at the end.

Bibliography lists the reference sources that were used in the research.

Appendix A contains the final drawings for the three prototypes.

Appendix B contains the results log for the evaluation.

Chapter 2

Research

2.1 Extent and nature of reverse driving problems

Driving in reverse is no easy task. It demands significant perceptual, cognitive and motor attentiveness to the driving environment[48, 49]. The driver has to constantly observe the surroundings, mentally process the received visual information to detect danger or obstacles, while maneuvering the vehicle by controlling the steering wheel and foot pedals. In order to avoid backing into obstacles, the driver must first be able to perceive or be alerted to an object in the backing path, recognize it as a hazard, and respond by applying the brakes fast and hard enough to stop the vehicle before reaching the obstacle.

Every year in the U.S., 228 fatalities and 17,000 injuries are caused by passenger vehicle backover crashes[1] [4]. Most incidents occur in non-traffic situations, off public roadways, in areas such as driveways and parking lots and involve parents (or caregivers) accidentally backing over their children.

The overrepresentation of young children under 5 years old in the number of backover crash fatalities is of great concern, as evidenced by the considerable effort in raising awareness to the problem[18, 39]. It has also motivated NHTSA[2] to conduct extensive, long-term research into technologies that seek to improve rear visibility of vehicles[4, 36].

This section discusses in detail the human factors issues concerning the use of such technologies based on the reports by NHTSA and other relevant human factors research on driving tasks.

[1] A backover crash is a specifically-defined type of incident, in which a non-occupant of a vehicle (i.e., a pedestrian or cyclist) is struck by a vehicle moving in reverse.

[2] National Highway Traffic Safety Administration, U.S. NHTSA was established by the Highway Safety Act of 1970 to carry out safety programs previously administered by the National Highway Safety Bureau[2].

2.1.1 Limited rear visibility

Behind almost every vehicle, there is an area or zone in which a driver cannot see, not just a spot. This can be referred to as a blind zone (Fig. 2.1). It is measured as the distance "behind a vehicle that a 28-inch traffic cone had to be before the person, sitting in the driver's seat, could see its top by looking through the rear window"[39]. This can differ "due to a combination of a vehicle's height, vehicle length, the driver's seating height, head restraint positions, and the rear window location/dimensions"[36].

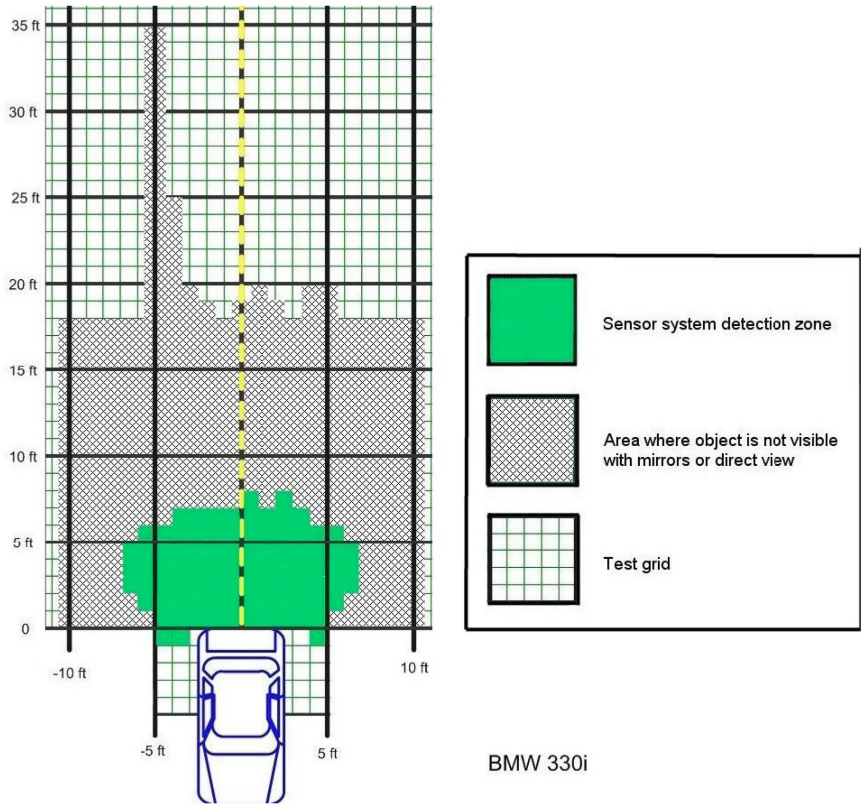


Figure 2.1: Example of blind zone. Image taken from [4].

Most vehicles have large blind zones[36]. In a recent data published by Consumer Reports[39], the average blind zone of mid-sized sedans ranges from 13ft (4.0m) to 22ft (6.7m) when measured for drivers of height 5ft 8in (1.73m) and 5ft 1in (1.55m) respectively. In the case of 2010 Toyota Prius, the vehicle used in this thesis, the measured blind zone ranges from 6ft (1.8m) to 10ft (3m). While the blind zone of the Prius is considerably lower than the average, it is worthy to note that simply looking at visibility by these measurements may not fully represent the risk induced by limited rear visibility. The actual rearward view of the Prius (Fig.2.2) is very much obscured by the backseat which makes visually detecting small obstacles, such as small children, extremely difficult.

Figure 2.2: Driver's view of the rear in a Toyota Prius.

Clearly, unlike forward driving, it is not possible to get a complete picture of the rear view solely by direct vision. Therefore the driver has to rely on a number of devices for indirect vision[3]. The most common type of devices are mirror systems.

[3]United Nations Economic Commission for Europe enacted Regulation 46 (ECE R46) defines devices for indirect vision as those that observe the area adjacent to the vehicle which cannot be observed by direct vision, including "conventional mirrors, camera monitors or other devices able to present information about the indirect field of vision to the driver.", Uniform Provisions Concerning the Approval of: Devices for Indirect Vision and of Motor Vehicles with Regard to the Installation of these Devices.

Mirror systems

Figure 2.3: (a) interior and (b) side rearview mirrors.

A basic system which is typically installed in a vehicle, consists of one interior and two side rearview mirrors (Fig.2.3). Interior rearview mirrors are mounted on the roof of the interior, providing the reflected view through the rear window. Side rearview mirrors are mounted at the base of the frontmost pillars on the exterior, presenting the views along the sides of the car. There are planar and convex versions for both mirrors, with the latter presenting a wider field of view.

Figure 2.4: (a) backing and (b) crossview mirrors.

Backing mirrors and "cross-view" mirrors (Fig.2.4) are additional convex mirror devices that provide views of the rear blind zone. Backing mirrors are mounted on the upper center of the rear window, allowing the driver to see the area behind the vehicle. They require a vertical rear window and hence are commonly found installed on school buses, short delivery trucks, vans and SUVs[4]. "Cross-view" mirror can be integrated into the inner face of both rearmost pillars or attached to the rear window to show objects approaching on a perpendicular path behind the vehicle. Both types of mirror may be viewed directly by glancing behind or indirectly through their reflection in the interior rearview mirror.

[4]Sports Utility Vehicle.

Mirrors are useful visual aids as they are "always on" and do not require power to operate. However, there are a number of disadvantages.

First, with convex mirrors, the image of reflected objects tend to be distorted. While a wider field of view is achieved by compressing the reflected image, objects and pedestrians appear very narrow and difficult for the driver to discern and identify in most locations within the reflected image. Distances are also distorted, often causing drivers to overestimate the distances from objects.

Second, the reflected images tend to be small. This is especially the case for rear-mounted backing mirrors and "cross-view" mirrors. Furthermore, the image quality worsens as the length of the vehicle increases, because the mirrors are further away from the driver[4].

Lastly, drivers are subject to mental image rotation[5] effect when observing the rear environment through the mirrors. Because the reflected images of the rear environment in the rearview mirror or side mirrors are laterally inverted (i.e. rotated 180°), it takes a longer time for drivers to determine the left and right orientation of the rear environment.

Rearview camera systems

From the discussion above, it can be concluded that mirrors do not provide a good view of the area behind the vehicle. Hence, they may be supplemented by another type of devices for indirect vision called rearview camera systems.

Figure 2.5: (a) Fusion Sport and (b) Lexus rearview camera systems.

[5]Mental rotation is the ability to rotate mental representations of two-dimensional and three-dimensional objects[55]. This phenomenon was first discovered by Roger Shepard and Jacqueline Metzler (1971). In an experiment they conducted, subjects were asked to determine whether two 2-dimensional pictures portray objects of the same 3-dimensional shape even though the objects are depicted in different orientations. It was found that the response time increased as the angular difference between the 2 pictures increased[42].

In such as system, a video camera is mounted on the rear of the vehicle, and the captured image is sent to a visual display (i.e. video screen) incorporated into the dash or into the interior rearview mirror (Fig. 2.5). Looking directly at the display allows the driver to see the area directly behind the vehicle, with a view of field performance that varies from approximately 130° to 180°, depending on the camera specifications. The video screen usually serves another purpose of providing a visual display for a navigation system or satellite radio. The screen size can range between 6in to 7in diagonal[1], which gives a maximum screen dimension of 156mm by 92mm for an aspect ratio of 16:9.

As compared to mirror systems, rearview camera systems provide a single wide field of view to the rear. In a 2006 review of three rearview camera systems[29, 30], NHTSA found that the examined systems provided a clear image of the rear blind zone in daylight and indoor lighting conditions. Pedestrians or obstacles behind the vehicle at a distance of 23 ft (7m) or more can be seen through the displays, except for an area within 8-12 in (20-30cm) of the rear bumper at ground level. An area as wide as the rear bumper at the immediate rear of the vehicle is displayed by the systems[4].

However, image quality is highly dependent on screen resolution and size. A low resolution display will make objects and people difficult to discern from the environment. The maximum screen size of displays (7in), not dissimilar to that of a side mirror, may not be big enough to clearly display all the visual information captured from the rear camera. In addition, the driver is likely to suffer similar cognitive effects that are experienced when using mirror systems. First, when observing the mirror image displayed on the video screen, mental image rotation effect is experienced. While it is possible to laterally invert the image before displaying to the driver, it is more ergonomic to display it as a mirror image so that it is consistent with the views from the rearview mirrors. Second, objects and pedestrians in the distance are more difficult to see due to the image and distance distortion effects of wide-angle lens cameras used in the systems (Fig.2.5).

2.1.2 Fragmented visual information

With mirrors and camera-display systems, it would seem plausible that their combined use and direct vision would completely eliminate the rear blind zone and hence afford the driver a complete view of the area behind the vehicle. However, in reality, the driver is not able to effectively use every visual information source at the same time. This is due to 1) a limited functional field of view and 2) the high display eccentricities.

Every human has a useful visual field known as the functional field of view. It is defined as "the total visual field area in which useful information can be acquired without eye or head movements (i.e. within one eye fixation)"[5]. Measured from the fovea[6], it is bounded 35° on the horizontal meridian and 25° on the vertical meridian. The region measured 10° from the fovea, known as parafoveal, is responsible for clear vision. Objects that are seen within this region can be clearly observed.The region beyond the 10°, known as peripheral, is characterized by poor vision acuity but is useful for detecting abrupt or contrasting changes that will guide the eye to look at the target stimuli[57].
On the other hand, the display eccentricities[7] exceed the range of the FFoV. Because of this, the driver often has to switch attention from one visual information source to another by eye and head movements. For instance, when looking at the right-side rearview mirror, the driver is unable to observe the video screen as the horizontal eccentricity is degrees, which is beyond the 35° horizontal limit of the FFoV. This inevitably means that a time-delay is incurred every time an attention-switch is made and that the driver may not be aware of changes that might occur in the other views. Furthermore, there is strong evidence to suggest that the FFoV degrades in driving task with increases in demand[9, 20, 33, 44] which, in this case, may be brought about by the constant need for attention-switching.

Devices for indirect vision	Horizontal eccentricities (°)	Vertical eccentricities (°)
Interior rearview mirror	0	0
Right side rearview mirror	97.5	38.8
Rearview camera monitor	26.9	53.8
Left side rearview mirror	9.6	38.8

Table 2.1: Display eccentricities in a Toyota Prius.

[6]Centre of the retina of the eye which has the highest acuity of vision.
[7]Angular differences measured from the point of observation between the visual information sources.

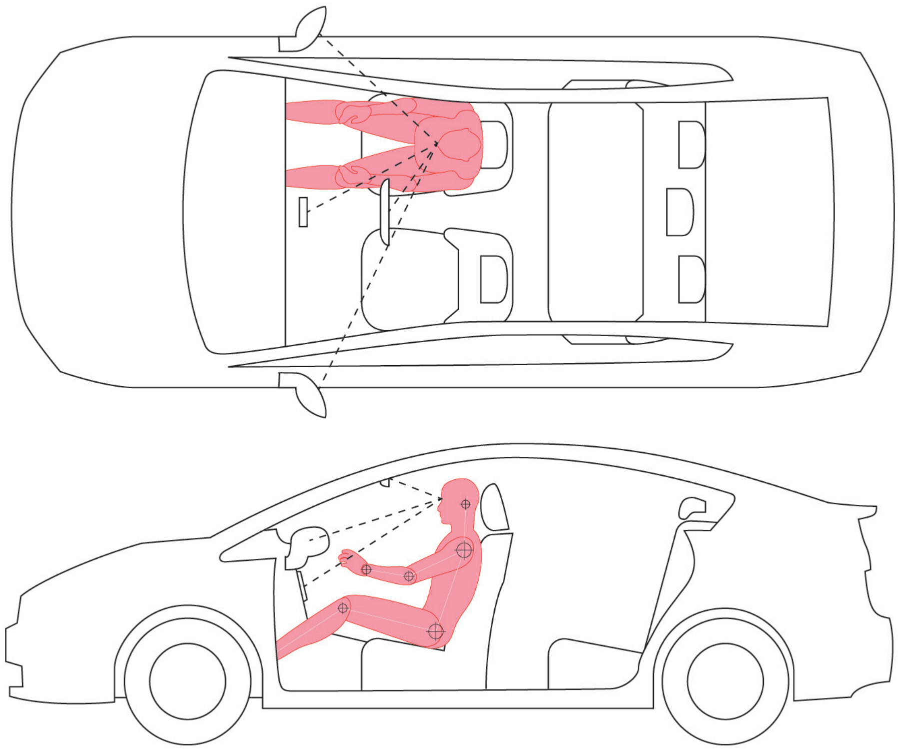


Figure 2.6: Horizontal and vertical eccentricities of the devices for indirect vision that are installed in a vehicle. They are measured from the middle of the display at their various positions. The interior rearview mirror is the reference display.

Such glance behaviour of drivers also has a significant effect on the effectiveness of rearview camera systems[4]. Drivers usually glance at the display at the start of a backing maneuver[31], and on average look at the visual display twice, or about 8-12 percent of the time[4]. In one study conducted to understand the effectiveness of rearview camera systems in reducing backing crashes in field experiments, it was found that only 20 percent of the participating drivers looked at the camera before backing[15]. These findings suggest that the rearview camera system is typically used only as an additional source of visual information complementing the views provided by the interior and exterior rearview mirrors, which may not be enough to detect a pedestrian in time to react.

Other studies have found that high display eccentricities pose safety concerns. The distribution of multiple displays (e.g. speedometer and rearview camera display) requires more visual scanning time inside the car resulting in a distraction from the outside road scene and increasing cognitive load[6, 11, 34]. In one study to determine the effects of different onboard display positions to driving tasks, it was found that the positions furthest away from the driver's line-of-sight to the primary task, the interior rearview mirror and the bottom of the middle console, were the worst positions[57]. These results also reflect previous findings that reaction times to hazardous signals increase substantially, especially for vertical display eccentricities[8, 43]. In response to NHTSA's enquiry on the use and efficacy of rearview camera systems, Nissan[8] has warned against over-reliance on rearview camera system as the driver can fail to see a person or an object positioned outside the camera's field of view. Nissan also stated that drivers should "always confirm clearance of the entire path of travel, and turn around and look during a backup maneuver"[4].

2.1.3 False warnings

Apart from vision-based technologies, sensor-based warning systems have been used as an alternative source of information about the rear blind zone. The systems use sensors (ultrasonic or radar) mounted in the rear bumper to detect obstacles and provide a signal (auditory tone, visual or both) to indicate the presence of, and distance to, obstacles behind the vehicle.

While sensor-based warning systems do not require the active visual attention of the driver to detect objects, they are 1) limited in range, 2) inoperative at higher speeds (above 3 to 6 mph), and 3) inconsistent in object detection[4, 36]. In particular, the inability to consistently detect objects behind the vehicle is a cause for concern, as this implies that the system will emit a warning in the absence of a real threat, i.e., a false warning.

In a NHTSA study, the agency found that sensor-based warning systems 1) often failed to detect a human, especially a small moving child, and 2) when detected, the resulting warning did not induce drivers to pause more than briefly in backing[4]. Several other studies on the effects of false warnings[3, 24, 58] have shown that drivers who experienced false warnings responded slower to imminent conflict. In the worst case, drivers simply ignored the warnings even if they may be real[25, 32]. Ilaneras et al.[25] concluded that "many drivers appeared to want direct sensory confirmation of the existence of an object before initiating immediate hard braking."

From the aforementioned findings, it appears that relying primarily on sensor-based warning systems may be dangerous and hence it is imperative that drivers are able to directly observe the rear blind zone instead.

[8]Nissan Motor Company Ltd.

2.2 Related works

The limitations of current solutions described in the previous section have led many researchers to seek novel ways to expand the rear field of view. In this section, three types of work are described: 1) panoramic vision, 2) bird's eye view vision, and 3) augmented vision.

2.2.1 Panoramic vision

Rearview camera systems are already capable of providing a wide-angle view (2.1.1). However, some research have found ways to capture an even wider (or 360°) view around the vehicle.

Most proposed systems use omni-directional cameras or panoramic sensors in different configurations: 1) monocular mounted on the rooftop[12, 21], 2) binocular[13, 14, 28], or 3) multi-camera systems[50]. In monocular systems, the captured raw image is un-warped using a Cartesian to polar coordinate system transformation to generate a panoramic image map of the surrounding environment. For binocular and multi-camera systems, an additional step to merge the transformed images of each camera view is required to generate a single unified panoramic surround map. The resulting panoramic surround maps do provide a large field of view. However, they are usually low in image resolution. Hence, they are primarily used for vehicle, object or pedestrian detection, or to estimate range to objects[28] but are not effective as visual displays of the surroundings (Fig.2.7).

Figure 2.7: Panoramic vision. Image taken from [27].

Others have designed panoramic systems as visual aids. Rickesh et al.[40] proposed a system using two video cameras mounted at the rear of the vehicle. The image feed from the cameras are aligned and merged into a single view. However, the panoramic image is displayed through a headgear which the driver is required to wear while using the system. This is impractical for actual driving.

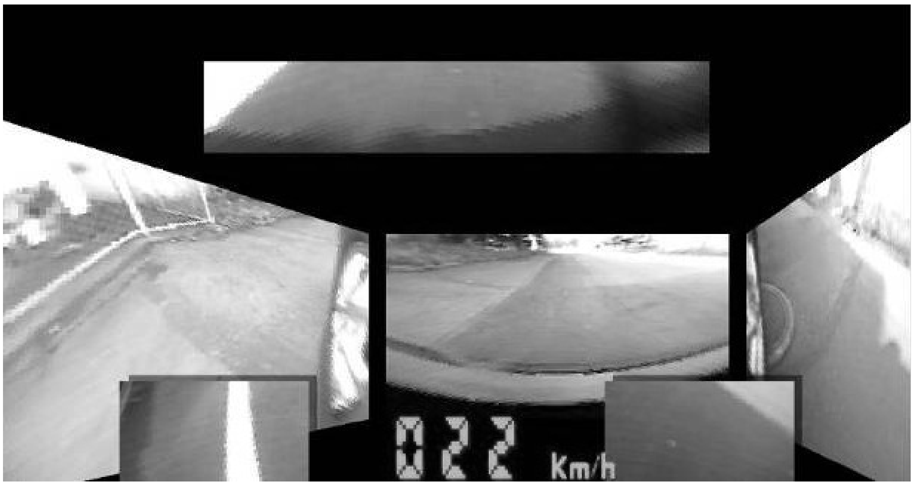


Figure 2.8: Panoramic presentation display. Image taken from [19].

Kuroki et al. proposed a panoramic presentation with a single display[19]. It consists of 6 fisheye cameras with a visual coverage of 165° mounted on the perimeter of the vehicle. The captured images are presented in 6 views (front, rear, left, right, rear left and rear right) on a 15 inch LCD monitor (Fig.2.8). Another stereo camera is mounted in front of the driver to detect his/her head orientation. This information is used to dynamically change the views presented on the LCD. For instance, when the driver looks to the left, the views presented will be the panoramic images on left side of the car. While this seemed useful, the system was found to be confusing to use for novice drivers. The authors also noted that the drivers were not able to confirm their surrounding situation when they gazed at the screen. This further reinforces previous findings that additional amount of information can also tax the driver's processing capabilities[51, 56].

2.2.2 Bird's eye view vision

The second type of work relating to view expansion is Bird's eye view vision. The idea is to create a virtual camera view in which to observe the vehicle and the surroundings from.

Okamoto et al.[37] first proposed a method called Virtual Viewpoint Image Synthesis. Using a 2-camera system, the captured images are mapped onto a 3D space as world coordinates on a plane (which corresponds to the road surface in the real world) using inverse perspective transformation. The mapped world coordinates are then converted using perspective transformation to the pixels of a virtual viewpoint image taken by a camera set at an arbitrary location. The resulting image allows the driver to see the surroundings from a high vantage point (i.e. a bird's eye view) above the vehicle.

Figure 2.9: Nissan Around View Monitor.

A commercial parking aid, Nissan Around View Monitor (Fig.2.9), was subsequently developed based on this technology[46]. Similar systems have also been proposed with improvements using multiple fisheye cameras[22, 23]. While they are useful as parking aids, these systems suffer from 1) low image resolution, 2) distortion of non-ground-level objects, and 3) amplified vibration in the farther surrounding area. Okamoto et al.'s method, in particular, faces severe ghosting effect at the blending zone of the images. As a result, objects that lie in the blending zone may not be recognizable.

2.2.3 Augmented vision

The third and final approach to expanding the rear view is by means of augmented reality[9] to overlay real-time information with the physical view.

Pardhy et al.[38] proposed a virtual mirror (i.e. visual display) that accurately reproduces the reflected image of a real mirror but with a wider view. A video camera is positioned to capture the image of the physical mirror and display it

[9]Augmented reality (AR) is a live, direct or indirect, view of a physical, real-world environment whose elements are augmented by computer-generated sensory input such as sound, video, graphics or GPS data[52].

onto a screen with additional Global Positioning System (GPS)[10]. information such as lane stripe and road furniture. Tonnis et al.[47] used a Head-Up Display (HUD)[11] system to present visualizations that actively assist the driver to visualize the source of danger. 3D arrows, projected as an overlay on the windscreen, point toward the direction where a vehicle, object or pedestrian may be detected. Both solutions are useful in their own right but, again, do not actually provide a wider view of the rear.

Yoshida et al.[59] proposed the concept of a transparent cockpit, in which the image of a blind zone is displayed on the interior of the vehicle using retroreflective projection technology[16]. This allows the driver to virtually "see through" the walls of the vehicle and observe the blind zones and the immediate surroundings together (Fig.2.10). This expansion of direct vision is useful, however in this setup, the driver is required to wear a head-mounted projector in order to use the system.

Figure 2.10: Transparent cockpit. Image taken from [59].

[10]The Global Positioning System (GPS) is a space-based satellite navigation system that provides location and time information in all weather, anywhere on or near the Earth, where there is an unobstructed line of sight to four or more GPS satellites. It is maintained by the United States government and is freely accessible to anyone with a GPS receiver[53].

[11]A head-up display or heads-up display - also known as a HUD - is any transparent display that presents data without requiring users to look away from their usual viewpoints. The origin of the name stems from a pilot being able to view information with the head positioned "up" and looking forward, instead of angled down looking at lower instruments[54].

2.3 Novelty of ThroughView

ThroughView is an augmented vision system that allows the driver to "see through" the back seat, based on the transparent cockpit concept (2.2.3). It expands the direct vision of the rear environment by merging with captured camera image into a single view, and hence avoids the human factors issues related to existing solutions (Table 2.2). However, unlike the transparent cockpit concept, it does not require the driver to wear an apparatus in order to use.

Current solutions	Rear blind zone visibility	Mental rotation	Image and distance distortion	Small view	Fragmented view	High display eccentricities	False warnings	Impractical to actual driving
Direct vision	x	-	-	-	-	-	-	-
Mirrors	x	x	o	x	x	x	-	-
Rearview cameras	-	x	x	x	-	x	-	-
Sensor-based warning system	x	-	-	-	-	-	x	-
Panoramic vision	-	x	o	o	-	x	-	o
Bird's eye view vision	o	x	o	x	-	x	-	-
Augmented vision	-	-	-	-	-	-	-	o

Table 2.2: Current solutions and the related human factors issues; present: 'x', partially present: 'o', not present: '-'.

The system has the following advantageous characteristics:

- **No additional view.** The rear view is expanded without adding an extra view that could further stress the driver[51, 56].
- **Natural line of sight.** The camera image is projected onto the obscured areas within the rear field of view and hence naturally closest to the line of sight. This implies that attention-switching between the camera image and direct vision of the rear surroundings can be achieved without significant head or eye movements of the driver, or mental image rotation effect.
- **No learning required.** Unlike rearview camera systems, the driver does not need to learn how to observe the expanded view. This is because ThroughView is designed around the intuitive way of looking back towards the rear.

- **Larger view.** The rear visual information is presented in its actual size, as it would be seen from the driver's viewpoint. In doing so, the viewable image size may be larger than that of current displays (i.e. mirrors and camera-monitors), which may make identifying obstacles easier. With a calibrated system, image and distance distortion effects may also be avoided.

Additionally, ThroughView may benefit women drivers more. First, mental image rotation effect is greater for women than men[45]. Second, the navigation strategies employed by women may be different from those of men. In one study, it has been found that women requires a wider field of view to achieve similar navigation performance to men in a virtual environment[10]. Both of these issues may be mitigated by the use of ThroughView.

Chapter 3

Design & Implementation

3.1 Concept

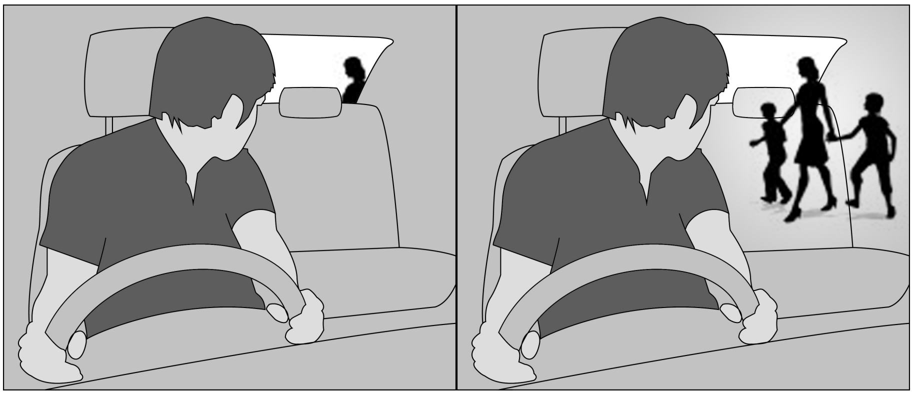


Figure 3.1: Experience sketch; (a) current situation, (b) with ThroughView.

ThroughView is an in-vehicle visual assistance system that allows the driver to "see through" the backseat and observe the area behind the vehicle.

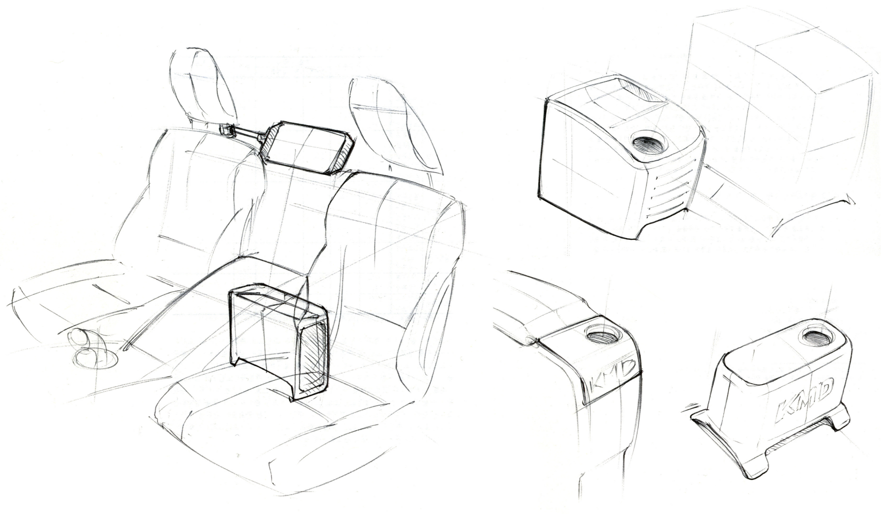


Figure 3.2: Concept sketch of ThroughView.

To create this experience, we propose a system that consists of a camera, a projector/processor device, a semi-transparent display and a retroreflective screen seat cover. The camera captures the image of the rear environment, sends it to the projector/processor device in the car, which displays it onto the retroreflective screen. The driver is able to observe both the projected image on the backseat through the semi-transparent display and the physical environment through the rear window in a single view.

3.2 Methodology

To realize this concept, an iterative process of designing, prototyping, implementing and testing (Fig. 3.3) is employed.

Figure 3.3: Design process of ThroughView.

In the design phase, key dimensions and constraints, such as the positions of the camera, projector and display, are first checked in the car interior to ensure that the concept works. Key features of the car interior, such as the centre armrest and headrest, are measured and noted down for later design considerations. Sketches are then used to generate ideas while mockups are quickly built to verify the viability of those ideas.

Next, selected ideas are further developed in the prototype phase. Paper mock-ups are constructed to ascertain the size and fit of the designs. Once confirmed, computer-aided drawings (CAD) of the designs are created in parts to allow for easy fabrication and assembly. Prototyping tools, such as laser cutting machine and 3D printer, are then used to create the actual parts.

Finally, in the implementation and testing phase, the assembled parts are installed in an actual vehicle and evaluated by the team. Minor problems, such as size of semi-transparent display and tilt angle of the camera, are quickly fixed and re-prototyped, while major issues, such as ergonomics and position of view-point, are noted down for the next iteration of the design.

The above-described process is repeated several rounds in order to achieve a more refined design of ThroughView.

3.3 Initial brief and specifications

Before starting the design process, certain guidelines has to be established. This section describes the initial brief and specifications for the design of the three prototypes. They are built to fit into an actual Toyota Prius.

3.3.1 Design brief

To design and build a visual assistance system that allows the driver to virtually ”see through” the backseat and observe the area behind the vehicle when reverse driving. For fast iterations, the system will be built using the prototyping tools available within the school. The finished prototype will be retro-fitted into a rental Toyota Prius.

3.3.2 Design specifications

Based on the above constraints, the systems should meet the following specifications:

Performance

- Projected display should be observable in outdoor, day condition.
- The system should be functional while the car is in operation.

Aesthetics

- The appearance should fit the interior of the Toyota Prius.

Environment

- There should be no destructive modifications to the interior of the Toyota Prius.

Technology

- The system will utilize retroreflective projection technology.

Safety

- The prototype should have no sharp corners.
- The prototype should be securely fastened to the interior environment.

Ergonomics

- The system should allow the driver to comfortably observe the projected display and the rear environment at the same time.
- The prototype should not obstruct the driver's operation of the vehicle.

Adjustability

- The system should allow for iterations of half-mirror size.
- The system should allow for quick adjustments of the angle and position(vertical and horizontal) of the half-mirror display.
- The system should allow for iterations of the projector position.
- The projector should be accessible.

Prototyping

- Parts should be produceable using the 3D printer(Dimension bst 768), laser-cutter(Commax Laser System Value Direct-7050 60W) and other available workshop tools.
- Parts should be quickly and easily replaceable for testing and design iterations.

3.4 First prototype

Figure 3.4: First prototype fitted into the Toyota Prius.

The first prototype is a two-camera, single-viewpoint system. The half-mirror display is placed at the left side of the headrest. The viewpoint is set at a position which the driver would typically look through when glancing toward the rear. The other units are mounted behind the driver, clear from the movements of the driver's arms that are required for operating the steering wheel or centre console.

Based on the specifications outlined in the previous section, several possible configurations for the placement of the projector and half-mirror in the car interior were considered. There were two options: 1) a single structure on which both the projector and half-mirror are mounted and 2) a two-unit design whereby the projector and half-mirror are mounted separately. The second option was finally chosen for its simplicity of construction and adjustability.

3.4.1 System design

The system is designed based on the retroreflective projection technology. It consists of: 1) two cameras(Microsoft Lifecam Studio Web Camera), 2) a processor(Lenovo X201s), 3) a projector(Taxan KG-PL011S), 4) a half-mirror(3mm, transmissivity:30%), and 5) a retroreflective backseat screen. Additionally, a black screen is attached to the ceiling of the interior to reduce unwanted reflec-

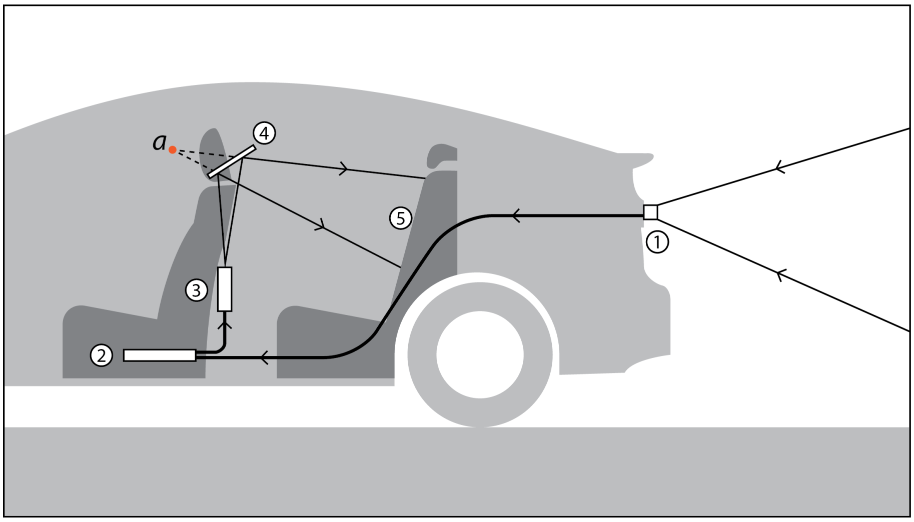


Figure 3.5: System schematics of the first prototype.

tions. A portable battery(Succor-300 DC-AC Inverter) is used to provide power to the system.

The flow of visual information is as follows:

- **Capturing.** The video images of the rear environment is first captured by the cameras and sent through USB wired connection to the processor.
- **Processing.** The received data is merged and corrected for exposure distortion (saturation, brightness, contrast) and image distortion (rotation, tilt, size, position).
- **Displaying.** After correction, the processed video is sent to the projector, which projects the final image onto the retroreflective screen by reflecting off the half-mirror. The retroreflective screen reflects most of the light back in the direction that it came from, and hence, the final image may be observed through the half-mirror display at viewpoint a (Fig. 3.5).

3.4.2 Part design

Three elements in the system require physical fixtures to hold them in position: the camera, the projector and the half-mirror.

Camera holder

The camera holder is a single, 3D printed part mounted on the rear exterior of the Prius by removable double-sided adhesive tape. The holder is angled so that the camera can be attached to point downward. This is so that the captured

Figure 3.6: Two cameras fixed at the rear of the car.

view follows the natural line-of-sight of the driver and shows a larger area of the blind zone. Iterations of the camera holder with different angles were made, and the 20° holder was finally implemented. A minimal profile design is used so that iterations can be quickly printed.

Projector case

The projector case is mounted onto the rear end of the centre armrest using removable double-sided adhesive tape and foam pads. It consists of three parts: top case, base and top bezel. The 3D printed top case holds the projector in a vertical position. The front and side openings on the case allow access to the controls(buttons, knob) of the projector. The top opening allows the projector to be inserted or removed. The base is also 3D printed. Besides interfacing with the centre armrest, it provides access to the ports of the projector(VGA, power) and serves as wire management. The laser-cut, acrylic, top bezel holds a wide conversion lens(Panasonic, VW-LW3707M3, $\times 0.7$ ϕ37mm) in place and has air vents for heat dissipation. It conceals the projector and completes the case.

The case is designed in two parts for two reasons. First, the total height of the case design exceeds the printing limit of the 3D printer(203mm $\times$ 203mm $\times$ 305mm). Second, to cater to possible changes to the prototype(such as height of projector) during testing, reprinting only the base will save time and material.

Aesthetics-wise, an extruded box shape is used to convey the line of projection. Generous fillets were given to complement the soft feel of the interior. A natural white ABS material is chosen to be 3D printed, as it matches the warm grey palette of the interior.

Figure 3.7: Projector case and mirror arm.

Mirror arm

The mirror arm is secured onto the headrest structure by tight-fit. It consists of three parts: arm, core and half-mirror display. The 3D printed arm connects to the left vertical column of the headrest structure and may be rotated around the column. It holds the 3D printed core, which may be extended outward by 50mm. The laser cut, acrylic half-mirror display is inserted into the core and held by tight fit at a default angle of 45° with a rotation limit of 22.5° about the axis of the core. A frame shape is etched onto the half-mirror display to help guide the driver to observe through the viewpoint.

The two-axis of rotational freedom and one-axis of translational freedom of the mirror arm allows for fine-tuning of the projected image position. Several sizes of the half-mirror display were tested to find the optimum balance between size and performance. The final size is L150mm × W170mm × H3mm.

The visual look follows that of the projector case. The half-mirror display was given large fillet corners not only to match the aesthetics of the system but also for safety.

3.4.3 Calibration

The video image is processed for exposure distortion (saturation, brightness, contrast) and image distortion (rotation, tilt, size, position) using a custom-written C++ program.

Figure 3.8: Calibrated image as seen from viewpoint.

To calibrate ThroughView, the following steps are taken:

1. **Set mirror rotation.** Turn the projector on. Set the laptop to display a white background in fullscreen mode. Rotate the half-mirror until the projected white background covers as much of the backseat screen as possible. Make sure the backseat headrests are covered by the projection area.

2. **Adjust image size and orientation.** Load the image processing program. Position a tall object or person as a visual reference 5m behind the vehicle. Observe the projected image from the viewpoint in front of the half-mirror. Move, scale and rotate the projected image using the controls in the image processing program until it closely matches the actual view of the visual reference.

3. **Adjust image exposure.** Next, adjust the saturation, brightness and contrast of the image using the program controls until the image is corrected as much as possible to that of the visual reference and environment.

4. **Save parameters.** Once an optimum is achieved, the angle of the half-mirror is fixed and the calibration parameters are saved. The same parameters will be loaded when the system is next turned on.

3.5 Second prototype

Figure 3.9: Second prototype fitted in the Toyota Prius.

The second prototype is a multi-camera, multi-viewpoint system. The configuration is similar to that of the first prototype except for an additional lens array that is placed between the projector and the half-mirror. A different projector(BENQ MX811ST) is also used instead for its short throw ratio of 0.61:1. The additional cameras capture a wider area of the rear blind zone, while the additional viewpoints serve to give the driver optional viewing positions to observe the projected image from.

3.5.1 System design

The system consists of: 1) four cameras(Microsoft Lifecam Studio Web Camera), 2) a processor(Lenovo X201s), 3) a projector(BENQ MX811ST), 4) a lens array, 5) a half-mirror(3mm, transmissivity:30%), and 6) a retroreflective backseat screen. As with the first prototype, a black screen is attached to the ceiling of the interior to reduce unwanted reflections. It is powered by a portable battery(Succor-300 DC-AC Inverter).

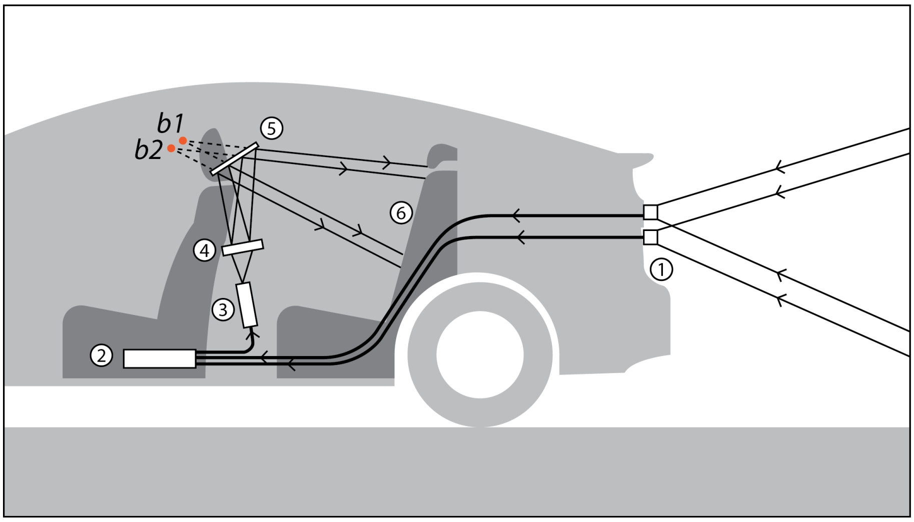


Figure 3.10: System schematics of the second prototype.

The flow of visual information is as follows:

- **Capturing.** The video images of the rear environment is first captured by the four cameras and sent through USB wired connection to the processor.
- **Processing.** The received data is first merged, then corrected for exposure distortion (saturation, brightness, contrast) and image distortion (rotation, tilt, size, position).
- **Displaying.** After correction, the processed video is sent to the projector, which projects it through the lens array. In the lens array, the projected light goes through two conversions. First, it is made parallel using a fresnel lens(ϕ500mm, f 250mm, pitch 0.5mm). After which, the light is refocused through four lenses (Edmund Optics, Achromatic Doublet Lens ϕ50mm, f 75mm, NT49-291), and reflected off the half-mirror onto the retroreflective screen. The retroreflective screen reflects the light back toward the half-mirror display, creating two viewpoints at *b1* and two others at *b2* (Fig. 3.10).

3.5.2 Part design

The system will share some of the parts used in the first prototype with little modifications. As the projector is different, a new case is required. In addition, a physical fixture to hold the lens array is required.

Camera holder

Figure 3.11: Four cameras fixed at the rear of the car.

The four cameras are mounted onto two sets of camera holders with angles 20° and 35°.

Lens array

The lens array is mounted onto the rear end of the centre armrest. It consists of three parts: lens holder, arm and base. The 3D printed lens holder is designed like a square container with an open bottom. The lenses are inserted into the holder with the fresnel lens(ϕ500mm, f 250mm, pitch 0.5mm) being the bottommost layer. The four lenses(Edmund Optics, Achromatic Doublet Lens ϕ50mm, f 75mm, NT49-291) are held in place by a sandwich of laser-cut acrylic frames. The lens holder is supported by a single 3D printed arm and may be rotated to change the angle of the lens array relative to the line of projection. The arm is bolted to the 3D printed base, which in turn grips onto the armrest with removable double-sided adhesive tape and rubber pads.

The rotatable lens array allowed adjustments of the light direction so that the images may be properly projected onto the half-mirror display.

Similar to the projector case of the first prototype, the visual look is kept clean and simple with minimal details and the use of natural white printing material.

Figure 3.12: Lens array of the second prototype.

Projector case

Figure 3.13: Projector case of the second prototype.

The acrylic projector case is mounted on the interior floor using removable double-sided adhesive tape and rubber pads. The design allows the projector to be inserted from the top and held at an angle of 10° by the side slots. The side and top of the projector is exposed to ensure effective cooling. The front opening provides access to the projector controls. Wires are hidden within the case and routed from underneath.

Acrylic construction for the case was chosen in favour of 3D printing due to the size of the projector. A single case designed to hold the projector would not be produceable by 3D printing in one run as it would exceed the printing size limit(203mm $\times$ 203mm $\times$ 305mm). Furthermore, it would be faster and cheaper to build the case out of laser-cut acrylic instead.

Mirror arm

The mirror arm remains unchanged. Half-mirror display size is increased to L200mm $\times$ W200mm $\times$ H3mm in order to accommodate the additional viewpoints.

3.5.3 Calibration

The calibration process for the second prototype follows the steps taken for the first prototype (3.4.3). As there are four viewpoints, steps 2 and 3 are repeated for each viewpoint.

3.6 Evaluation of the first and second prototypes

The two prototypes were implemented and tested in a rental Toyota Prius. The vehicle was driven within the school campus and backing maneuvres were executed with the use of the systems. Initial evaluations revealed several glaring issues.

- **Space consuming.** While the systems did not interfere with the driver's operation of the car, the setup took up substantial space above the centre armrest and in the leg space in the back passenger cabin. This is particularly so for the implementation of the second prototype, which made the centre backseat unusable. Furthermore, as a system that is used only in reverse driving situations, such demand for space is unreasonable.
- **Complicated calibration.** During field-testing, it was found that that while mounting the projector and the half-mirror separately offered flexibility in adjustments, calibration of the system became complicated. This is because whenever the seat position or tilt is changed(to accommodate different drivers), the relative position of the projector and half-mirror changes as well. Substantial time is required to re-calibrate.

- **Unergonomic.** Despite placing the half-mirror display as close to the left side of the driver as possible, the viewpoint is still in an unergonomic position. The driver has to extend his/her head further leftward in order to observe correctly. This is limited by the positions of the projector and half-mirror display.

- **Other issues.** The image display of the second prototype was inferior to that of the first prototype. There are two reasons: First, the image resolution of the second projector is shared by four images hence it is lower than that of the first projected image. Second, the images are degraded as they are converted through the fresnel lens. Another issue concerns the additional viewpoints of the second prototype. While they offer more viewing positions, it seems confusing to use as effort is taken to find a suitable viewpoint to observe through. Further tests are needed to ascertain the benefits of the multi-viewpoint system.

3.7 Third prototype

The final prototype focuses on achieving better integration with the car interior and improving the usability of the system by resolving the issues found with the first two prototypes(3.6). It is a single-camera, single-viewpoint system that is attached onto the driver seat. The projector is strapped onto the left back area of the seat. The half-mirror display is attached onto the headrest with a modified mirror arm.

Compared to the first two prototypes, this design is more compact and takes up less space in the car interior. The new locations of the projector and half-mirror display afford a more ergonomic viewing position for the driver as the viewpoint is moved closer to the left side of the headrest. In terms of calibration, it is much easier to implement as the relative position of the projector and the half-mirror is fixed.

Figure 3.14: Third prototype installed in the Toyota Prius.

3.7.1 System design

The system is similar to that of the first prototype(3.4.1). It consists of: 1) a camera(Microsoft Lifecam Studio Web Camera), 2) a processor(Lenovo X201s), 3) a projector(Taxan KG-PL011S), 4) a half-mirror(3mm, transmissivity:30%), and 5) a retroreflective backseat screen. Additionally, a black screen is attached to the ceiling of the interior to reduce unwanted reflections. A portable battery(Succor-300 DC-AC Inverter) is used to provide power to the system.

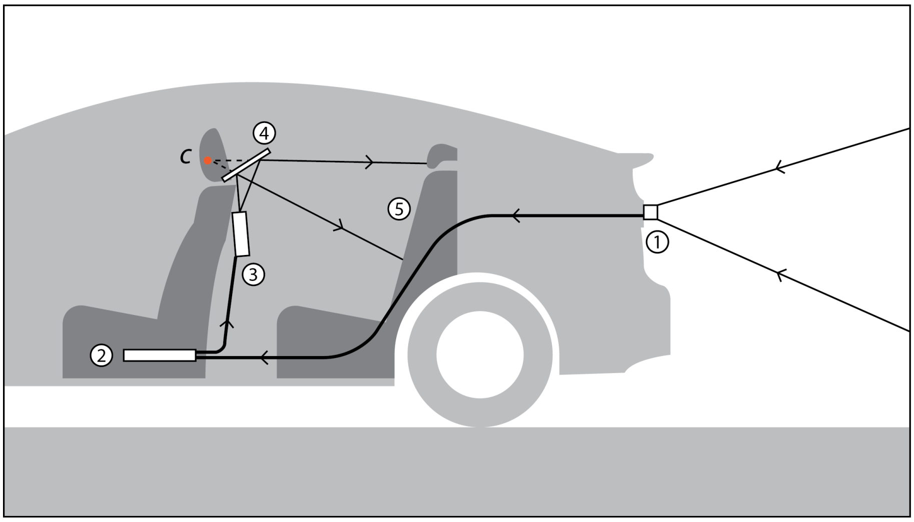


Figure 3.15: System schematics of the third prototype.

The flow of visual information is as follows:

- **Capturing.** The video image of the rear environment is first captured by the camera and sent through USB wired connection to the processor.
- **Processing.** The received data is corrected for exposure distortion (saturation, brightness, contrast) and image distortion (rotation, tilt, size, position).
- **Displaying.** After correction, the processed video is sent to the projector, which projects the final image onto the retroreflective screen by reflecting off the half-mirror. The retroreflective screen reflects most of the light back in the direction that it came from, and hence, the final image may be observed through the half-mirror display from viewpoint c (Fig. 3.15).

3.7.2 Part design

The projector case and the half-mirror display are designed based on the first prototype. Modifications are made to resolve the issues identified.

Mirror Arm

To shift the viewpoint closer to the side of the driver, the mirror arm is shortened by 50mm. Half-mirror display size is increased to L240mm × W200mm × H3mm to allow for maximum projection area.

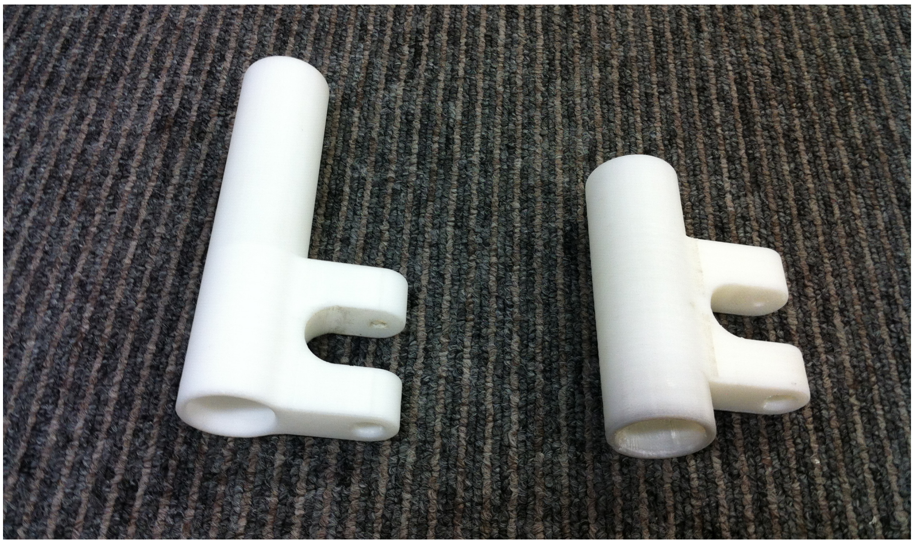


Figure 3.16: Mirror arms; (a) first prototype and (b) third prototype.

Projector case

The projector case is designed based on the top case of the first prototype. The fillets were enlarged to further reduce the box size and give it a softer feel. Vents were added on the sides of the case to improve airflow and heat dissipation. Similar to the first projector case, the projector is inserted and removed from the top opening which is covered by a black acrylic top bezel.The case was 3D-printed in black for a more professional look.

To successfully mount the case to the back of the seat, two additional accessories have to be designed. The first accessory is an acrylic angled base which is attached to the back of the case. This is used to constrain the tilt of the projector . The second accessory is a cloth harness and belt attachment. The case is secured to the seat using this harness. It is attached to the headrest structure by an acrylic bracket and fastened around the seat by a belt. The harness and belt is bolted and sandwiched between the projector case and angled base. This method of attachment was chosen for implementation as it does not require alteration to the car interior.

3.7.3 Calibration

The third prototype is calibrated in the same way as the first prototype (3.4.3).

Figure 3.17: Projector case of the third prototype.

Chapter 4

Evaluation

4.1 Evaluation aims

The ThroughView concept needs to be evaluated by drivers. The main question that I want to answer with my evaluation is whether ThroughView will be useful to drivers.

- Can ThroughView help drivers during backing maneuvres by expanding their direct vision of the rear environment?

In addition, I also wanted to find out the drivers' experience of using ThroughView for the first time, and how that compares with that of using the rearview camera system.

To answer these questions, a qualitative user study with a group of drivers is conducted. Driving tasks of backing a vehicle using the systems, interviews and observation studies are carried out to evaluate the usefulness of ThroughView and to understand the user experience.

4.2 Evaluation method

The evaluation is a set of driving tasks that involves backing a vehicle 20m along a straight path. The third ThroughView prototype system is installed in a rental Toyota Prius which is already equipped with a rearview camera system. Participants are put through four test scenarios (Table 4.1): 1) without aid, 2) with ThroughView system, 3) with rearview camera system, and 4) with both systems. Static and moving objects are introduced in the backing path of the vehicle in each scenario to simulate obstacle situations.

Test sequence	TV	RV	No. of runs	Static object	Moving object
Scenario 1	-	-	1	run 1	run 1
Scenario 2	x	-	5	run 1, 4	run 1, 3
Scenario 3	-	x	5	run 2, 4	run 2, 5
Scenario 4	x	x	1	run 1	run 1

Table 4.1: Test scenarios; ThroughView: 'TV', rearview camera: 'RV', active: 'x', inactive: '-'.

Scenario 1: without aid

The first scenario simulates a typical backing situation whereby drivers mainly use rearview mirrors and looking back to check the rear environment. Both static and moving objects are introduced in the backing path of the vehicle. This test is conducted in one run and used as a reference result for the subsequent tests.

Scenario 2: with ThroughView

The second scenario involves the use of ThroughView. As participants will be using the system for the first time, five runs will be conducted. This will allow them to learn and become accustomed to the system, and hence enable us to obtain more accurate feedback on the user experience. Obstacles will be introduced in three of the runs.

Scenario 3: with rearview camera

The third scenario involves the use of rearview camera system. For fair comparison of using the two systems, this scenario will also be run five times with three obstacle situations.

Scenario 4: with both systems

In the fourth scenario, participants are free to use both systems. Both static and moving objects are introduced in the backing path of the vehicle. As participants are already familiar with both systems, it is conducted only in one run.

In each scenario, participants are tested on whether they are able to see the obstacles in the backing path. If a participant momentarily stops the vehicle and sounds out that there is an object in the backing path, this will indicate a positive result. Further confirmation of the result is made during the interview.

When the participants are backing the vehicle, the strategies that the participants use to observe the rear environment are noted. The devices of indirect vision (p.7), i.e. ThroughView, rearview cameras and mirrors, that are used, the postures that participants adopt and other observed behaviour are recorded down. In-vehicle video footage of the participants are taken to aid observation.

After each run, the participants are interviewed on their experience of using the tested system. They are first asked to rate the use of the system on a 10-point scale. The ratings are then used as a reference to talk about their experience of using the system. For example, if there is an improvement in ratings after successive runs, the participants will be asked for the reason for the favourable change. Another use of the reference ratings is to make comparisons between the systems. If participants rate one system higher than the other, they are also asked for the reason for their preference. However, the ratings are not used as test results for analysis.

4.2.1 Test environment and setup

Figure 4.1: Test environment.

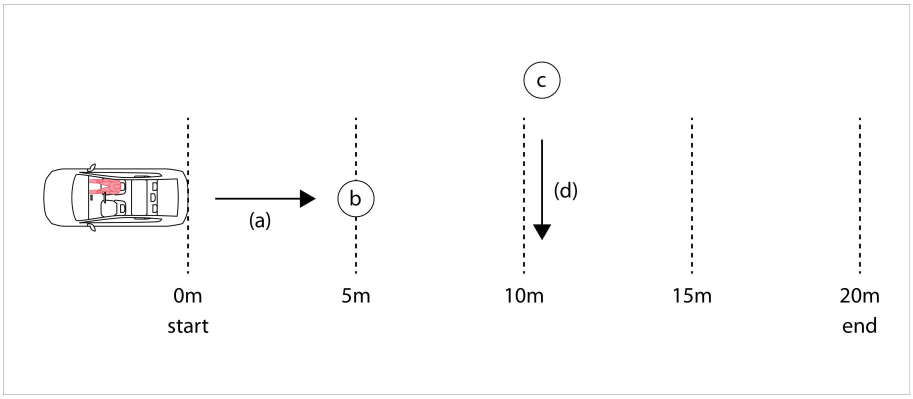


Figure 4.2: Test layout; (a) backing path, (b) static object, (c) moving object and (d) obstacle path.

The test is conducted within an enclosed area in a basement car park (Fig. 4.1). The test area is set up as shown in Fig. 4.2. The distance measured from the back of the vehicle to the wall at the end of the test area is approximately 20m.

The ThroughView system is installed onto the driver seat as per design (3.7). For in-vehicle video recording, a camera (Microsoft Lifecam Studio Web Camera) is mounted on the left corner of the dash and connected by wired USB to a laptop (Macbook Pro). Power is supplied to the equipment onboard the vehicle from an wall electrical outlet in the test area through a 50m power cord drum.

A baby doll is used as a static object and a soccer ball is used as a moving object for the obstacles (Fig. 4.3). For runs in which static objects are introduced, the baby doll is placed at the 5m mark center-aligned behind the vehicle and along the backing path. In the case of moving objects, the soccer ball is rolled from the left to the right at the 10m mark when the vehicle passes the 5m mark.

Figure 4.3: Obstacles for test; (a) Static object, baby doll and (b) moving object, soccer ball.

4.2.2 Test procedure

The user study was conducted with 8 participants (4 males and 4 females) of ages between 23 and 29, and heights between 1.53m and 1.81m. They have varying driving experience: 4 participants have driven at least 3 times on a weekly basis for 3 years while the rest have driven less than once a month. 6 out of 8 participants have no experience using the rearview camera monitor.

The participants were divided into 2 groups of four. One group was tested with following the test sequence described in Table 4.1, while the other group was first tested with scenario 3 (rearview camera) before tested with scenario 2 (ThroughView). This was done to mitigate any possible bias arising from the order effect. In particular, fatigue from, or familiarity with use of one system might affect the opinion regarding the use of the other system.

The following steps were taken in the conduct of the test.

Pre-test

1. Participant sits in the driver seat. Tester sits in the front occupant seat.
2. Participant familiarizes with the controls of the vehicle.
3. Participant practices backing the vehicle until he/she is comfortable with handling the vehicle.
4. Tester obtains basic information about the participant before starting the tests.
5. Tester briefs Participant about the driving task, test sequence, number of runs and the locations of both systems. No instructions are given on how to use either systems.

Test scenarios (for each run)

6. Participant backs vehicle until the end point is reached.
7. Tester notes how Participant observes the rear environment and whether he/she sees the obstacles.
8. Tester interviews Participant on his/her experience.

Post-test

9. End of test.
10. Tester reviews recorded video for further observations.

4.3 Results

4.3.1 Obstacle detection

Test results	Static object observed	Moving object observed
Scenario 1	0 (0%)	2 (25%)
Scenario 2 run 1	7 (87.5%)	7 (87.5%)
Scenario 2 run 3	-	8 (100%)
Scenario 2 run 4	8 (100%)	-
Scenario 3 run 2	8 (100%)	8 (100%)
Scenario 3 run 4	8 (100%)	-
Scenario 3 run 5	-	8 (100%)
Scenario 4	8 (100%)	8 (100%)

Table 4.2: Test results; not tested: '-'.

In test scenario 1, all the participants did not see the static object when backing. Only 2 participants saw the moving object through the right rearview mirror.

In test scenario 2 using ThroughView, all except one participant was able to see the obstacles that were introduced in the backing path. The exceptional participant was not able to observe the obstacles because he did not figure out how to use the system on the first run. He was observing the rear environment through the interior rearview mirror and could faintly see the projected image on the backseat screen but not enough to see the obstacles in the backing path.

In test scenario 3 and 4, all participants were able to see the backing path using the tested systems.

Evidently, the results have shown that ThroughView does expand the direct vision of the rear environment and can help drivers see the rear blind zone during backing maneuvres under the test condition.

4.3.2 Observation and feedback

Observation made during the test and feedback from the participants have highlighted some interesting aspects of the ThroughView system.

Obscured view

Some participants commented that it was easy to switch between ThroughView and the physical view of the rear environment. However, observation shows that some participants would raise their head or even body in order to look out

Figure 4.4: Observation; one participant raised up to look from above the half-mirror display.

the rear window. When asked, participants said that the half-mirror display darkened the view and made it difficult to see the rear environment clearly.

Difficulty in maintaining a look-back posture

Figure 4.5: Observation; one participant maintained the look-back posture by holding onto the armrest.

Compared to the rearview camera, almost all participants found it tiring to maintain a constant posture of looking back when using ThroughView. One participant who had a stiff back commented that ThroughView would be difficult to use for those who suffer from back problems.

Limited field-of-view

All participants mentioned that the field of view provided by ThroughView was too narrow. They felt that the amount of visual information was insufficient. With the rearview camera, they were able to see not only the entire backing path but also to its two sides. Using ThroughView, however, participants were only able to see the obstacles when they appear directly behind the vehicle. As a result, they felt less confident using the system when responding to obstacles as they had less time to react and hence had to brake suddenly.

Intuitive to use & ergonomic viewpoint

No operating instructions were given prior to the test. Nevertheless, all except one participant was able to find the viewpoint to observe from and use ThroughView intuitively without any help on the first try.

Distance perception

Several participants mentioned that they could perceive distances better with ThroughView. They felt that the projected image matches real-world sizes and hence were more trusting toward the system. For this reason, many participants used ThroughView for visual confirmation when the vehicle was reaching the end point near the wall in test scenario 4.

Tool for obstacle confirmation

Some participants mentioned that they would use ThroughView to have a close-up look when they encounter an obstacle. In the test scenario 4, it was observed that some participants initially used the rearview camera system to look at the rear environment. When an obstacle was encountered, they used ThroughView to have a second look. They felt the image provided by ThroughView was bigger and clearer. In this respect, some felt both systems could well in tandem.

Chapter 5

Conclusion

5.1 Discussion

The results of the evaluation in the previous chapter has shown that ThroughView can to a certain extent help expand the direct view of the rear environment. However it also revealed some limitations of the final prototype system. This section discusses the implications of those findings to future development work and the possibility of commercialization.

5.1.1 Limitations of the system

Narrow field-of-view

First, the narrow field-of-view provided by ThroughView is a major limitation of the system. With the current implementation, the projected image measures 670mm × 380mm on the backseat but only the central-rear blind zone is visible to the driver. The other parts of the rear blind zone - 1) the area directly behind the driver, 2) the left-rear corner and 3) the left C-pillar - are all not visible using the system. From a human-factors perspective, it is not easy for the driver to observe the entire rear blind zone even if ThroughView was able to provide a complete view. In particular, the area directly behind the driver cannot be observed by the typical look back glance but instead requires the driver to turn back with considerable effort. It is, therefore, important that drivers are aware of this limitation or are supplemented by additional visual information. Furthermore, the observed behaviour of drivers alternating between the two tested systems in test scenario 4 also hints at the fact that ThroughView may not be relied on solely as the primary tool for looking at the rear blind zone.

Obscured view

Second, the half-mirror display obscures the physical view of the rear environment. When switching attention between ThroughView and the physical view, drivers tend to raise their head or body to look over the display. As the use of half-mirror in this system is inevitable, this behaviour suggests that a redesign of the mirror size and the use of a half-mirror of higher transmissivity are necessary iterations to provide a more comfortable viewing experience.

Difficulty in maintaining a look-back posture

Third, the difficulty in maintaining a look back posture for long periods suggests that the system may not be suitable for a constant viewing behaviour, i.e. for general survey of the rear blind zone. Instead, the system may be more ideal to support specific and purposeful glancing behaviour observed in test scenario 4, such as having a closer look at the obstacle in the backing path.

5.1.2 Further design development

Apart from examining the usability issues of the system, it is also important to consider the general approach to further develop ThroughView, there are two possible directions to consider: ThroughView as an integral part of the driver seat or as an attachable aftermarket product.

Integrated design

Figure 5.1: Interior of Subaru Outback 2012.

Integrating electronics to the seat are not common in present-day passenger vehicles, but newer models and concept vehicles are beginning to show this possibility. 7-inch DVD screens embedded onto the front headrests are available as options on the Subaru[1] Outback 2012 (Fig. 5.1). The Hyundai[2] Blue2 concept car (Fig. 5.2) features rotatable tablet-like screens. Brabus[3] iBusiness (Fig. 5.3) is a super tuned Mercedes[4] S600 which comes with headrest screens, a 15.2 inch

[1]Subaru of America, Inc. http://www.subaru.com/index.html
[2]Hyundai Motor America. http://www.hyundaiusa.com/
[3]Brabus. High-performance aftermarket car tuning company. http://www.brabus.com/en/index.html
[4]Mercedes-Benz USA, LLC. http://www.mbusa.com/mercedes/index

TFT screen above the centre armrest and additional tablet screens stored in the back of the front seats.

Figure 5.2: Interior of Hyundai Blue2 concept car.

Figure 5.3: Interior of Brabus iBusiness.

ThroughView can be incorporated into the driver seat design (Fig. 5.4) in a similar fashion To achieve better integration with the car interior. In such a design, the projector is mounted on the left back area of the seat, while the half-mirror display is integrated into the headrest. During forward driving operations, the system is inactive and hidden. When switching to reverse driving, the half-mirror display extends out from the side of the headrest and rotates to an appropriate angle to allow the camera image to be projected onto the backseat retroreflective screen.

Figure 5.4: Sketch of the integrated design.

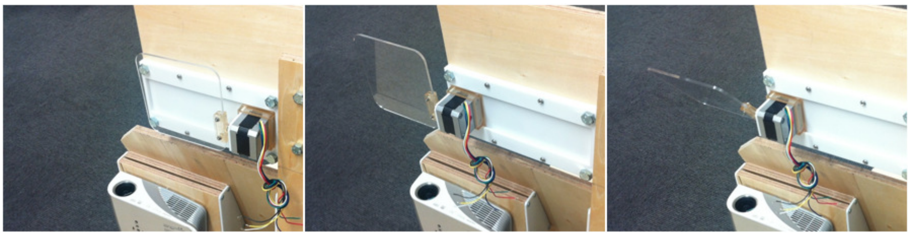


Figure 5.5: Half mirror display integrated to headrest; (a)hidden position, (b) extended position and (c) mirror rotated to an appropriate angle.

Compared to the current implementation, this design is more compact and takes up less space in the car interior. Furthermore, being integrated into the seat and only active during reverse driving, the system poses less safety concerns as there are no protruding fixtures in the interior.

Figure 5.6: Integrated design; proof-of-concept.

One advantage of an integrated design approach is that the quality of the ThroughView experience can be controlled. Calibration of the system can be set at factory without much effort from the user. However, this approach implies that collaboration with a car maker is necessary in order to realize the design.

Attachable design

Another way of incorporating electronics into the car interior is by attaching it onto interior features such as the headrest. One such aftermarket solution is the Seatback solutions (Fig. 5.7) by Audiovox[5] which seamlessly integrate to the back of the seat without alterations. Pyle[6] PLD76GR Adjustable Headrest with Built-In 7-Inch TFT/LCD Monitor kit (Fig. 5.8) replaces factory installed headrest. Pioneer[7] Carrozeria AVIC-ZH99HUD (Fig. 5.9) adds head-up display capabilities by attaching to the sun visor above the driver seat.

Figure 5.7: Seatback solution by Audiovox.

Figure 5.8: Pyle adjustable headrest with built-in monitor.

[5]Audiovox. Supplier of automotive aftermarket products. http://www.audiovoxproducts.com/

[6]Pyle. Supplier of high-end car audio equipment. http://www.pyleaudio.com/Home.aspx

[7]Pioneer. Supplier of car navigation systems. http://pioneer.jp/

Figure 5.9: Pioneer Carrozeria HUD.

The current implementation of ThroughView follows this design approach by attaching to the driver seat and headrest structure. The clear advantage of this approach is that it can be installed in most vehicles without destructive modifications to the car interior. However, calibration may be difficult as it differs vehicle to vehicle and may require effort on the part of users. Hence, the quality of the ThroughView experience may vary.

5.1.3 Commercialization

Both the integrated and attachable design approach have their pros and cons. Without further development in either direction, it may be too early to discuss the possibility of commercializing ThroughView. Nevertheless, it is necessary to examine this issue from the perspectives of design, technology, business and policy.

From the design standpoint, the usability issues highlighted during the evaluation of ThroughView needs to be resolved. But more importantly, the value proposition of ThroughView needs to be properly defined moving forward. Should it be developed as a competitive solution to the rearview camera system or as a complimentary system? When this is made clear, design efforts can be channelled toward creating a desirable and appropriate user experience.

Technology-wise, alternative display technologies may be considered. The current implementation uses a LED projector and the image is projected onto the backseat. The main issue is that the backseat has to be left vacant in order to use the system. This is unreasonable in situations when there are occupants in the backseat. The other issue concerns the size of the device. The final implementation is still too bulky, despite a substantial size reduction from the first two prototypes. Form factor of the device may be reduced with a smaller projector, but more testing would be necessary to determine the minimum specifications for the system.

From the business perspective, cost is a major issue. The most expensive component in the current implementation of ThroughView is the Taxan KG-PL011S projector (69,500 yen[17], $878[8]). This is already significantly higher than the cost of installing a rearview camera system onto a truck[36] ($325). Hence, in terms of price and performance, the cost of ThroughView is not justifiable. Cost reduction is therefore necessary for ThroughView to be commercially viable.

Lastly, in terms of policy, ThroughView has to comply with government safety standards before it can be commercially available. Safety regulations, such as the Vehicle Safety Test Procedures stipulated by NHTSA[35], need to be consulted and incorporated into the design specifications. Currently, this is not implemented in the process.

5.2 Future work

This section describes the future research work that can be undertaken to further improve and develop the system.

5.2.1 Further testing

The evaluation conducted in this thesis involves only a simple straight path backing maneuvre; ThroughView was not tested with backing and turning, and other forms of maneuvre that might produce the mental image rotation effect. Also, ThroughView was tested only in the indoor car park environment. To ascertain the effectiveness of the system for visual assistance, it would need to be tested in a variety of weather and lighting conditions.

5.2.2 Expanding the field-of-view

Achieving a wider field-of-view is important to improving both the functionality and user experience of ThroughView. To do so, two aspects of the system have to be examined. First, the image capture has to be expanded. This can be done quite easily by using a multi-camera system such as the one used in the second prototype (3.5). Second, the image projection area has to increase. Using a projector with a wider throw may work but this requires further prototyping and testing to confirm.

[8]Based on conversion rates provided by Google. Accessed 19.06.2012

5.2.3 Auto-calibration

Auto-calibration would enable the system to adapt to different drivers or sitting positions. If the system is able to correct the projected video image to suit the seat tilt and position, users would not need to deal with the hassle of recalibrating ThroughView each time the seat is moved. More experiments and calculations would be required to determine the appropriate algorithm for this functionality to work.

5.2.4 Enhancing video image with additional information

ThroughView is a visual-only system. However, as with all visual-based systems, The effectiveness of ThroughView is seriously degraded in situations of poor visibility, such as driving in the rain, fog or at night. The use of night vision technologies [7, 26, 41] for image enhancement or detection of living objects, may be a possibility. Another option may be to include graphical overlay information. These visual information may or may not aid users. More research is required to determine the appropriate type of information and the manner of integration.

5.2.5 Interior ceiling as projection canvas

Because the backseat is used as a projection canvas for the camera image, this limits its practicality as no passengers can be present in the centre of the backseat. Additionally as retroreflective material or coating is required for the screen, this will limit the choice of seat covers and place an additional constraint on the car interior colour, trims and material. To resolve this problem, an alternative projection setup may be considered. The final image may be projected to the interior ceiling instead of the backseat. This approach, however, will require more exploration and testing to ascertain its effectiveness.

5.3 Summary of contributions

The idea of enabling the driver to see through the backseat of the car has been realized with the concept of ThroughView. The system, when installed in a car, can expand the direct vision of the rear environment for the driver using retroreflective projection technology.

Three designs of ThroughView have been iterated and produced as working prototypes. The first and second prototypes demonstrated the validity of the concept but were bulky, unergonomic and difficult to calibrate. Based on these findings, the third prototype was made smaller, the viewpoint adjusted to be easier to look through, and the projector unit attached onto the driver seat for easier calibration.

Testing with the third prototype has proved the efficacy of the system and uncovered some human factors issues. Drivers were able to find the viewpoint and use the system without help. Most drivers found the system useful during backing maneuvres, relying on it to check the rear blind zone when an obstacle was encountered. Most significantly, drivers found it easier to perceive distances on ThroughView than on the rearview camera system.

In closing, future plans for the system have been proposed. An integrated design approach was given as an alternative to the current attachable design and a proof-of-concept was built to demonstrate the possibilities. The issue of commercialization has been discussed from the perspectives of design, technology, business and policy. The current implementation is suitable as a complimentary solution to the rearview camera system. Moving forward, however, more testing and refinement are required before the system can be considered as commercially viable.

Bibliography

[1] Car tv monitors - buying car tv monitors. http://encyclopedia.jrank.org/articles/pages/cm278dutj4/Car-Tv-Monitors-Buying-Car-TV-Monitors.html. Accessed 24.04.2012.

[2] National highway traffic safety administration website. http://www.nhtsa.gov/. Accessed 24.04.2012.

[3] G. Abe and J. Richardson. The effect of alarm timing on driver behaviour: an investigation of differences in driver trust and response to alarms according to alarm timing. *Transportation Research Part F: Traffic Psychology and Behaviour*, 7(4-5):307–322, 2004.

[4] National Highway Traffic Safety Administration. Rear visibility; federal motor vehicle safety standard, rearview mirrors; federal motor vehicle safety standard, low-speed vehicles; phase-in reporting requirements. 2010.

[5] K.K. Ball, B.L. Beard, D.L. Roenker, R.L. Miller, and D.S. Griggs. Age and visual search: Expanding the useful field of view. *JOSA A*, 5(12):2210–2219, 1988.

[6] Y. Bao, M. Kiss, and M. Wittmann. Effects of age and memory grouping on simulated car driving. In *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, volume 46, pages 1853–1857. SAGE Publications, 2002.

[7] Josh Briggs. How in-dash night-vision systems work. http://electronics.howstuffworks.com/gadgets/automotive/in-dash-night-vision-system.htm.

[8] PC Burns, H. Andersson, and A. Ekfjorden. Placing visual displays in vehicles: Where should they go? In *International Conference on Traffic and Transport Psychology*. ICTTP, 2001.

[9] D. Crundall, G. Underwood, and P. Chapman. Driving experience and the functional field of view. *Perception-London*, 28(9):1075–1088, 1999.

[10] M. Czerwinski, D.S. Tan, and G.G. Robertson. Women take a wider view. In *Proceedings of the SIGCHI conference on Human factors in computing*

systems: Changing our world, changing ourselves, pages 195–202. ACM, 2002.

[11] D. De Waard. *The measurement of drivers' mental workload.* Traffic Research Centre VSC, Univ. Groningen, 1996.

[12] T. Gandhi and M. Trivedi. Parametric ego-motion estimation for vehicle surround analysis using an omnidirectional camera. *Machine Vision and Applications*, 16(2):85–95, 2005.

[13] T. Gandhi and M.M. Trivedi. Vehicle mounted wide fov stereo for traffic and pedestrian detection. In *Image Processing, 2005. ICIP 2005. IEEE International Conference on*, volume 2, pages II–121. IEEE, 2005.

[14] T. Gandhi and M.M. Trivedi. Vehicle surround capture: Survey of techniques and a novel omni-video-based approach for dynamic panoramic surround maps. *Intelligent Transportation Systems, IEEE Transactions on*, 7(3):293–308, 2006.

[15] D.S. Hurwitz, A. Pradhan, D.L. Fisher, M.A. Knodler, J.W. Muttart, R. Menon, and U. Meissner. Backing collisions: a study of drivers' eye and backing behaviour using combined rear-view camera and sensor systems. *Injury Prevention*, 16(2):79–84, 2010.

[16] M. Inami, N. Kawakami, and S. Tachi. Optical camouflage using retroreflective projection technology. In *Proceedings of the 2nd IEEE/ACM International Symposium on Mixed and Augmented Reality*, page 348. IEEE Computer Society, 2003.

[17] Kakaku. Price of taxan kg-pl011s projector. `http://kakaku.com/item/K0000066799/`. Accessed 19.06.2012.

[18] Kids and Cars. U.s child nontraffic incidents by year. `http://www.kidsandcars.org/statistics.html`.

[19] Y. Kuroki, T. Okino, T. Haraikawa, Y. Sakane, and Y. Takebayashi. Multimodal cruising assist to enhance the drivers' abilities to perceive surrounding contexts using panoramic presentation with dynamic multiple windows. In *Pervasive Computing and Communications Workshops, 2007. PerCom Workshops' 07. Fifth Annual IEEE International Conference on*, pages 429–434. IEEE, 2007.

[20] PN Lee and TJ Triggs. The effects of driving demand and roadway environment on peripheral visual detections. In *Australian Road Research Board Conference Proc*, volume 8, 1976.

[21] S. Li. Monitoring around a vehicle by a spherical image sensor. *Intelligent Transportation Systems, IEEE Transactions on*, 7(4):541–550, 2006.

[22] S. Li and Y. Hai. Easy calibration of a blind-spot-free fisheye camera system using a scene of a parking space. *Intelligent Transportation Systems, IEEE Transactions on*, 12(1):232–242, 2011.

[23] Y.C. Liu, K.Y. Lin, and Y.S. Chen. Birds-eye view vision system for vehicle surrounding monitoring. *Robot Vision*, pages 207–218, 2008.

[24] R.E. Llaneras. Exploratory study of early adopters, safety-related driving with advanced technologies. draft final task 2 report: In-vehicle systems inventory, recruitment methods & approaches, and owner interview results. Technical report, 2006.

[25] R.E. Llaneras, C.A. Green, R.J. Kiefer, W.J. Chundrlik Jr, O.D. Altan, and J.P. Singer. Design and evaluation of a prototype rear obstacle detection and driver warning system. *Human Factors: The Journal of the Human Factors and Ergonomics Society*, 47(1):199–215, 2005.

[26] Y. Luo, J. Remillard, and D. Hoetzer. Pedestrian detection in near-infrared night vision system. In *Intelligent Vehicles Symposium (IV), 2010 IEEE*, pages 51–58. IEEE, 2010.

[27] L. Matuszyk. Stereo panoramic vision for obstacle detection. 2006.

[28] L. Matuszyk, A. Zelinsky, L. Nilsson, and M. Rilbe. Stereo panoramic vision for monitoring vehicle blind-spots. In *Intelligent Vehicles Symposium, 2004 IEEE*, pages 31–36. IEEE, 2004.

[29] E. Mazzae and W.R. Garrott. Evaluation of the performance of available backover prevention technologies for light vehicles, 2007.

[30] EN Mazzae and WR Garrott. Experimental evaluation of the performance of available backover prevention technologies. *National Highway Traffic Safety Administration, DOT HS*, 810:634, 2006.

[31] EN Mazzae and WR Garrott. On-road study of drivers use of rearview video systems (orsdurvs). *National Highway Traffic Safety Administration*, 2008.

[32] S.B. McLaughlin, J.M. Hankey, C. Green, and R. Kiefer. Driver performance evaluation of two rear parking aids. In *Proceedings of the 18th International Technical Conference on the Enhanced Safety of Vehicles*, 2003.

[33] T. Miura. Active function of eye movement and useful field of view in a realistic setting. 1990.

[34] Y.I. Noy, T.L. Lemoine, C. Klachan, and P.C. Burns. Task interruptability and duration as measures of visual distraction. *Applied Ergonomics*, 35(3):207–213, 2004.

[35] National Highway Traffic Safety Administration U.S. Department of Transportation. Vehicle safety test procedures. `http://www.nhtsa.gov/Vehicle+Safety/Test+Procedures`. Accessed 01.05.2012.

[36] National Highway Traffic Safety Administration U.S. Department of Transportation. Vehicle backover avoidance technology study, 2006.

[37] S. Okamoto, M. Nakagawa, K. Nobori, A. Morimura, T. Okada, S. Masuda, and Y. Fujita. Development of parking assistance system using virtual viewpoint image synthesis. In *Proceedings of World congress on intelligent transport systems, 3075S*, 2000.

[38] S. Pardhy, C. Shankwitz, and M. Donath. A virtual mirror for assisting drivers. In *Intelligent Vehicles Symposium, 2000. IV 2000. Proceedings of the IEEE*, pages 255–260. IEEE, 2000.

[39] Consumer Reports. The danger of blind zones. `http://www.consumerreports.org/cro/2012/03/the-danger-of-blind-zones/index.htm`. Accessed 15.04.2012.

[40] TN Rickesh and B. Naveen Vignesh. Augmented reality solution to the blind spot issue while driving vehicles. In *Recent Advances in Intelligent Computational Systems (RAICS), 2011 IEEE*, pages 856–861. IEEE, 2011.

[41] K. Schreiner. Night vision: infrared takes to the road. *Computer Graphics and Applications, IEEE*, 19(5):6–10, 1999.

[42] R.N. Shepard and J. Metzler. Mental rotation of three-dimensional objects. *Science*, 171(3972):701–703, 1971.

[43] H. Summala, D. Lamble, and M. Laakso. Driving experience and perception of the lead car's braking when looking at in-car targets. *Accident Analysis & Prevention*, 30(4):401–407, 1998.

[44] H. Summala, T. Nieminen, and M. Punto. Maintaining lane position with peripheral vision during in-vehicle tasks. *Human Factors: The Journal of the Human Factors and Ergonomics Society*, 38(3):442–451, 1996.

[45] S.M. Tapley and MP Bryden. An investigation of sex differences in spatial ability: Mental rotation of three-dimensional objects. *Canadian Journal of Psychology/Revue canadienne de psychologie*, 31(3):122, 1977.

[46] Nissan Technology. Nissan around view monitor. `http://www.nissan-global.com/EN/TECHNOLOGY/OVERVIEW/avm.html`.

[47] M. Tonnis and G. Klinker. Effective control of a car driver's attention for visual and acoustic guidance towards the direction of imminent dangers. In *Proceedings of the 5th IEEE and ACM International Symposium on Mixed and Augmented Reality*, pages 13–22. IEEE Computer Society, 2006.

[48] National Research Council Transportation Research Board. Transportation in an aging society: Improving mobility and safety for older persons. vol 1. committee report and recommendations. *Transportation Research Board Research Report 218*, 1988.

[49] National Research Council Transportation Research Board. Transportation in an aging society: Improving mobility and safety for older persons. vol 1. technical papers. *Transportation Research Board Research Report 218*, 1988.

[50] M.M. Trivedi, T. Gandhi, and J. McCall. Looking-in and looking-out of a vehicle: Computer-vision-based enhanced vehicle safety. *Intelligent Transportation Systems, IEEE Transactions on*, 8(1):108–120, 2007.

[51] R. Van Der Horst. Occlusion as a measure for visual workload: an overview of tno occlusion research in car driving. *Applied Ergonomics*, 35(3):189–196, 2004.

[52] Wikipedia. Augmented reality. `http://en.wikipedia.org/wiki/Augmented_reality`. Accessed 24.04.2012.

[53] Wikipedia. Global positioning system. `http://en.wikipedia.org/wiki/Global_Positioning_System`. Accessed 24.04.2012.

[54] Wikipedia. Head-up display. `http://en.wikipedia.org/wiki/Head-up_display`. Accessed 24.04.2012.

[55] Wikipedia. Mental rotation. `http://en.wikipedia.org/wiki/Mental_rotation`. Accessed 24.04.2012.

[56] A.S. Wikman, T. Nieminen, and H. Summala. Driving experience and time-sharing during in-car tasks on roads of different width. *Ergonomics*, 41(3):358–372, 1998.

[57] M. Wittmann, M. Kiss, P. Gugg, A. Steffen, M. Fink, E. Pöppel, and H. Kamiya. Effects of display position of a visual in-vehicle task on simulated driving. *Applied Ergonomics*, 37(2):187–199, 2006.

[58] K. Yamada and J.K. Kuchar. Preliminary study of behavioral and safety effects of driver dependence on a warning system in a driving simulator. *Systems, Man and Cybernetics, Part A: Systems and Humans, IEEE Transactions on*, 36(3):602–610, 2006.

[59] T. Yoshida, K. Jo, K. Minamizawa, H. Nii, N. Kawakami, and S. Tachi. Transparent cockpit: Visual assistance system for vehicle using retro-reflective projection technology. In *Virtual Reality Conference, 2008. VR'08. IEEE*, pages 185–188. IEEE, 2008.

Appendix A

Prototype drawings

A.1 First prototype

This section contains the drawings for the first prototype.

1. Camera holder (20 deg)
2. Projector case

   Top case

   Top case - base plate

   Top case - projector plate

   Base

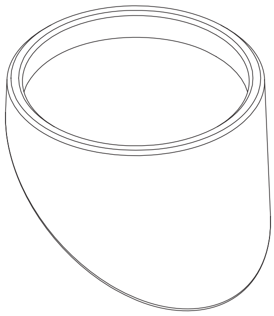
   Top bezel
3. Mirror arm

   Arm

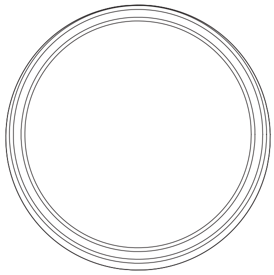
   Core

   Half-mirror display (150 $\times$ 170)

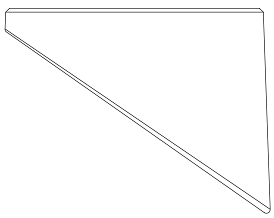
Part name: Camera holder (20 deg)	Scale: 1 : 1	Process/Material: 3D print - ABS



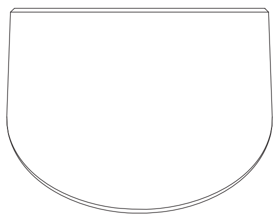
Perspective



Top

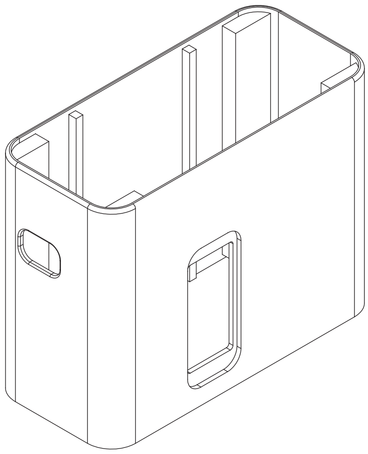


Side

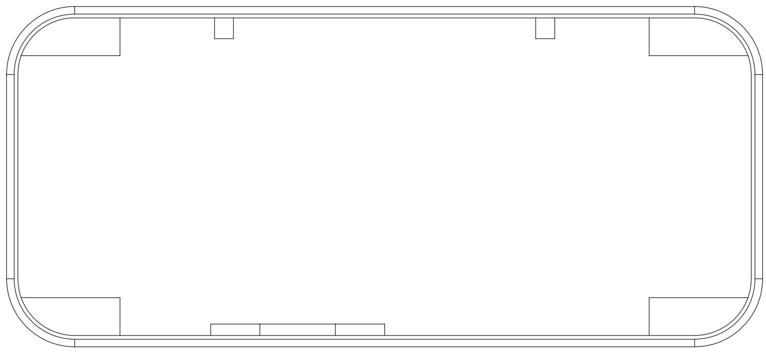


Front

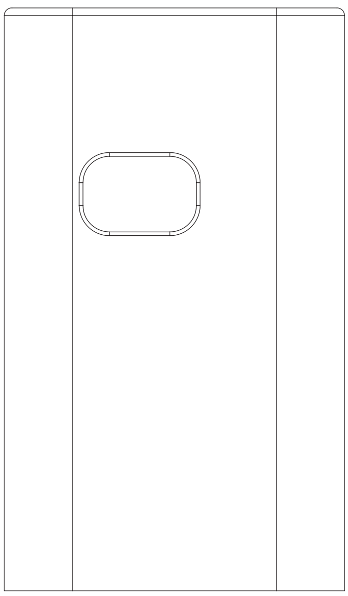
Part name: Projector case - top case	Scale: 1 : 2	Process/Material: 3D print - ABS



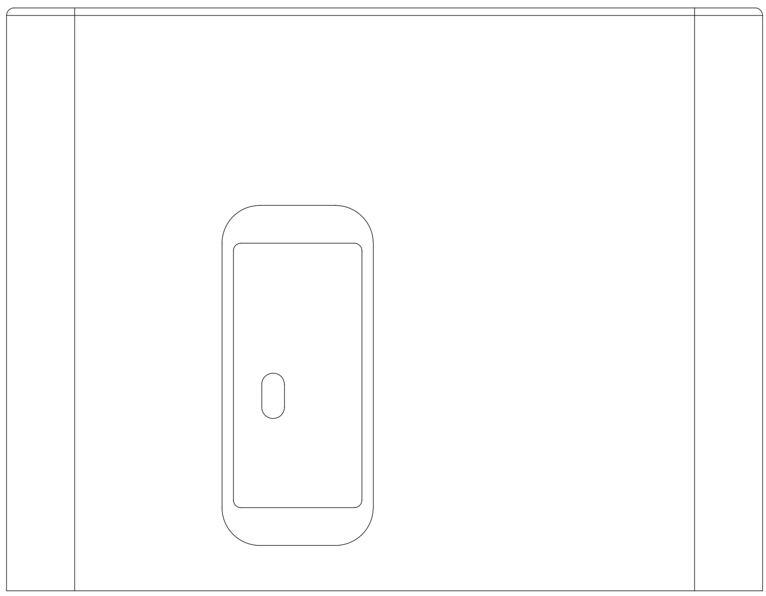
Perspective



Top

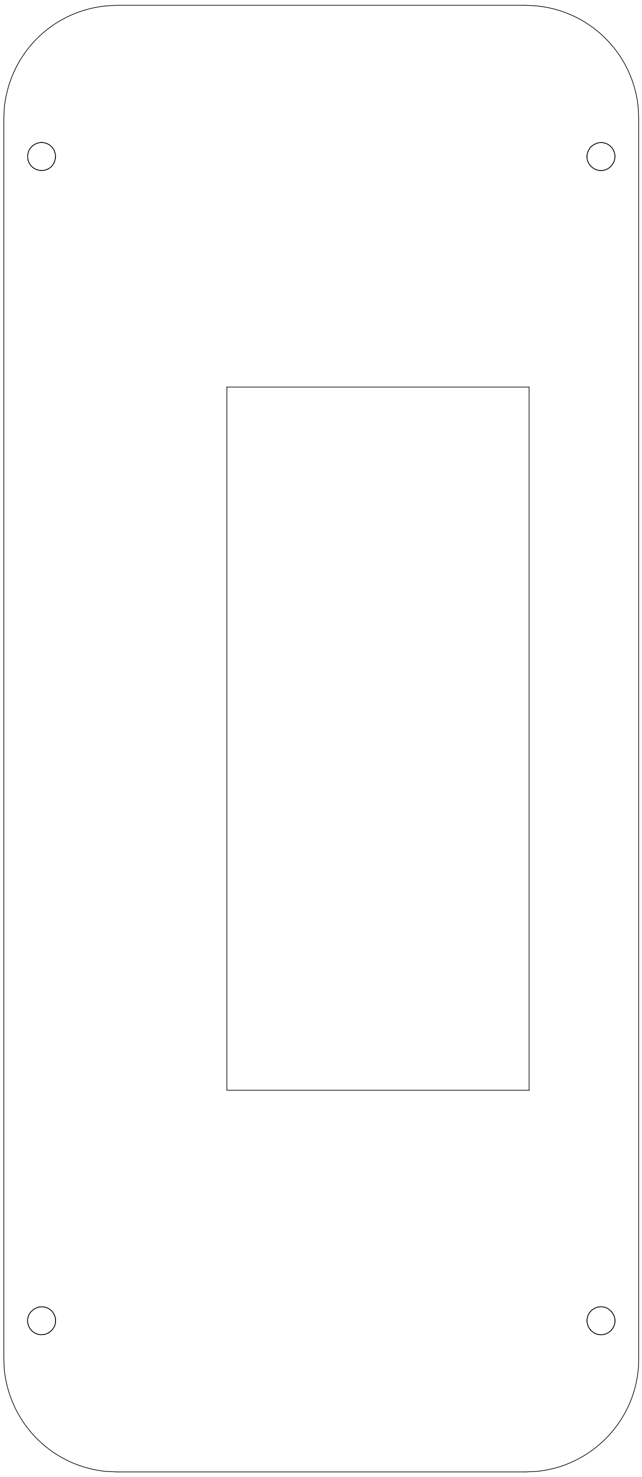


Side



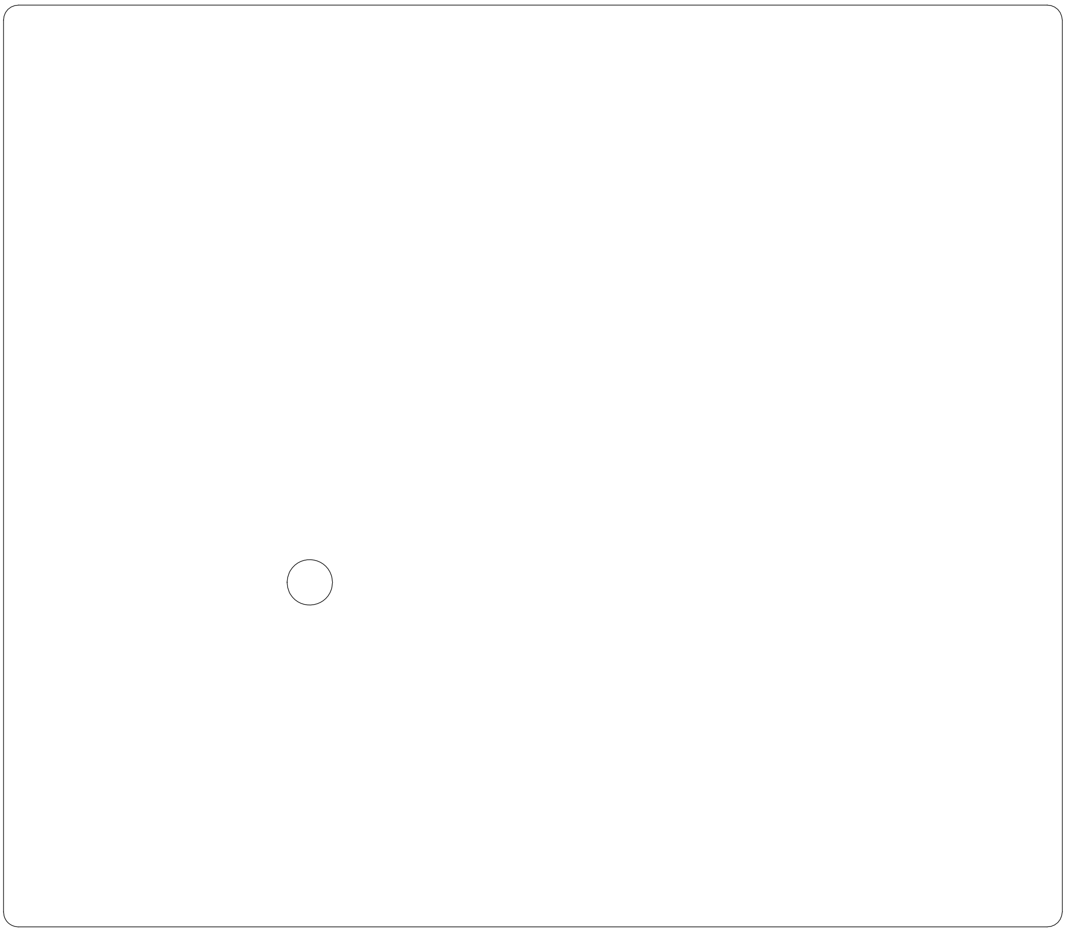
Front

Part name: Projector case - top case - base plate	Scale: 1 : 1	Process/Material: Lasercut - acrylic



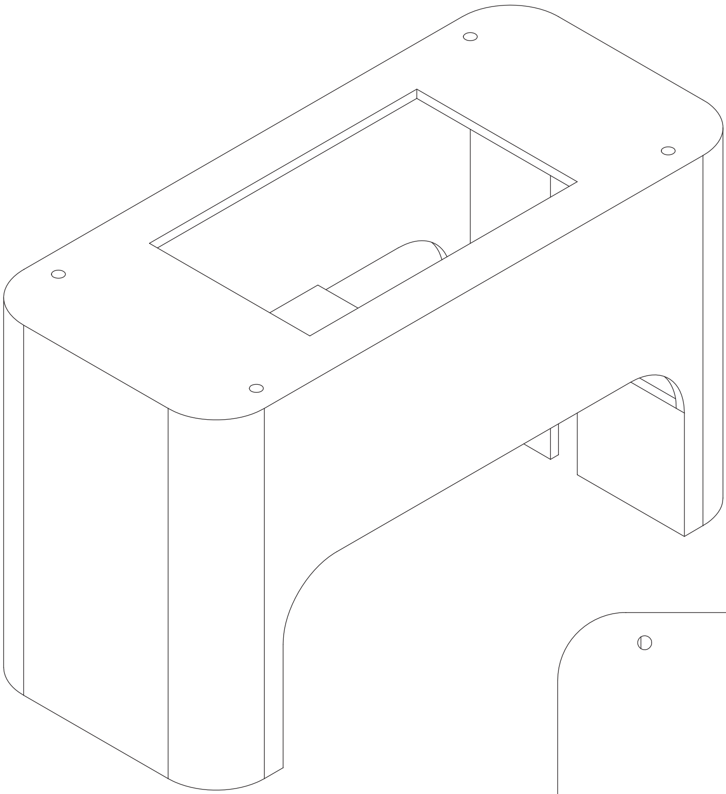
Top

Part name: Projector case - top case - projector plate	Scale: 1 : 1	Process/Material: Lasercut - acrylic

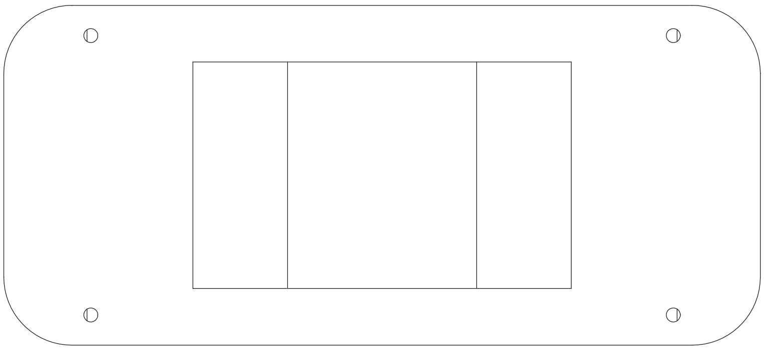


Top

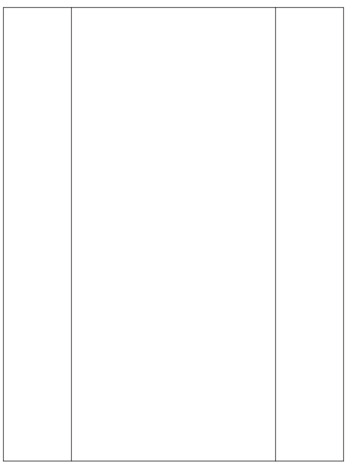
Part name: Projector case - base	Scale: 1 : 2	Process/Material: 3D print - ABS



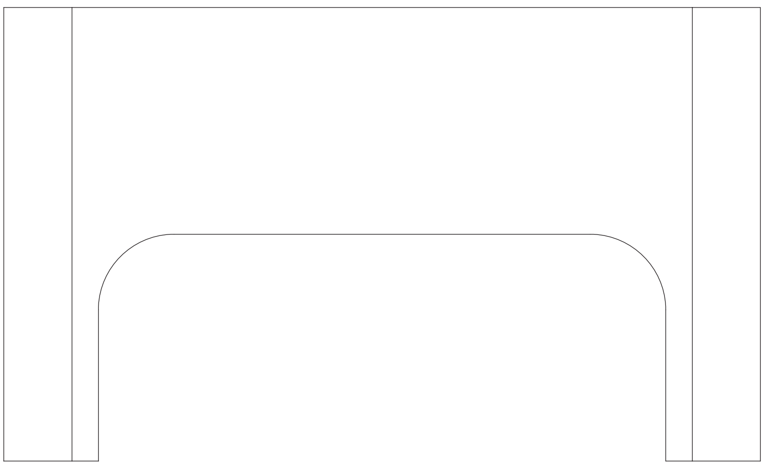
Perspective



Top

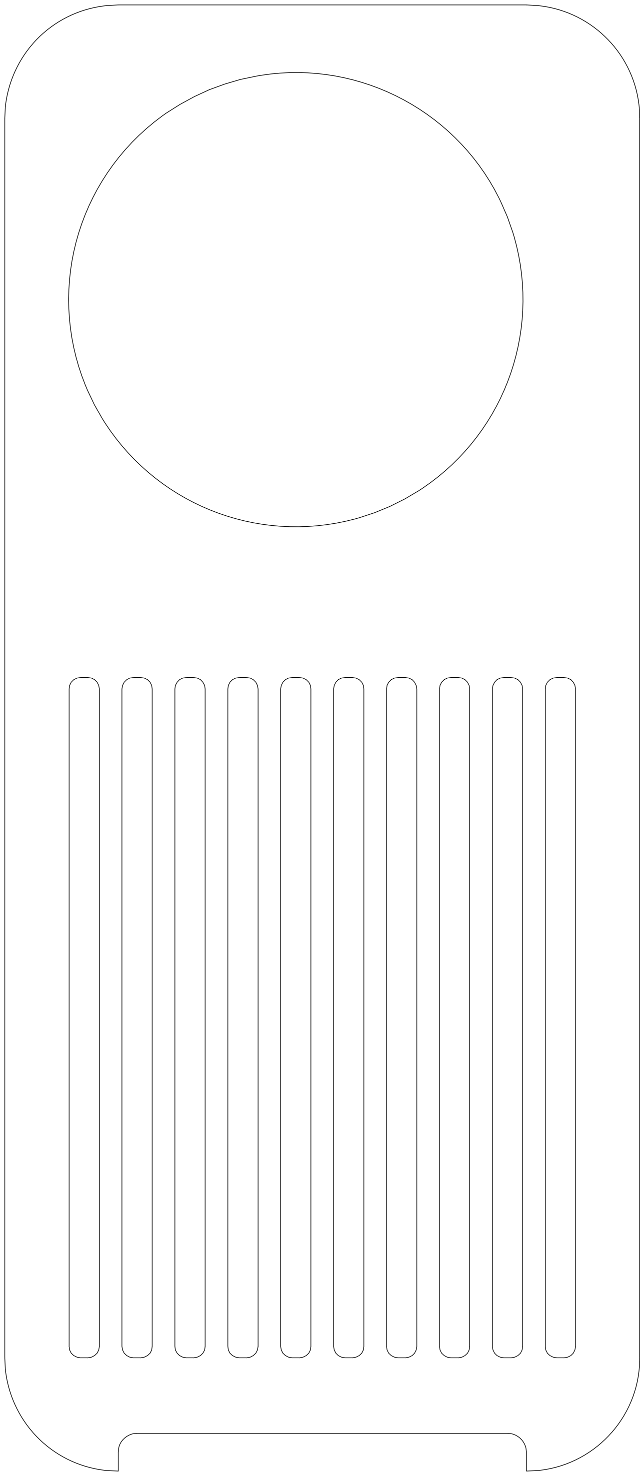


Side



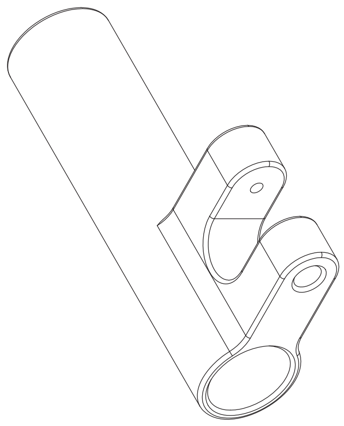
Front

Part name: Projector case - top bezel	Scale: 1 : 1	Process/Material: Lasercut - acrylic

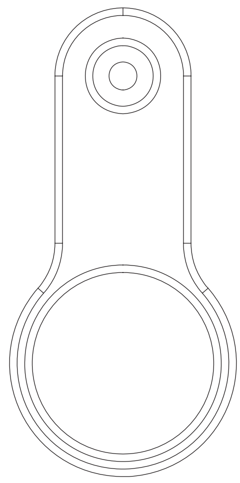


Top

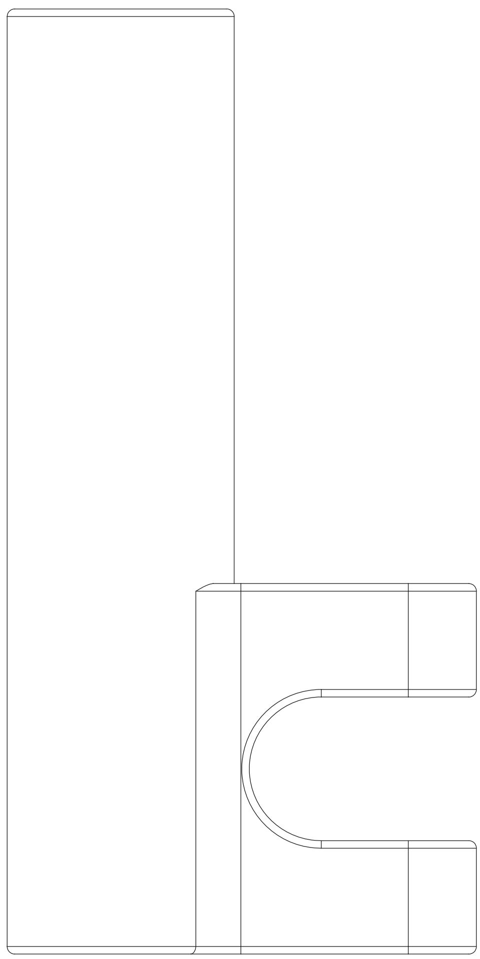
Part name: Mirror arm - Arm	Scale: 1 : 1	Process/Material: 3D print - ABS



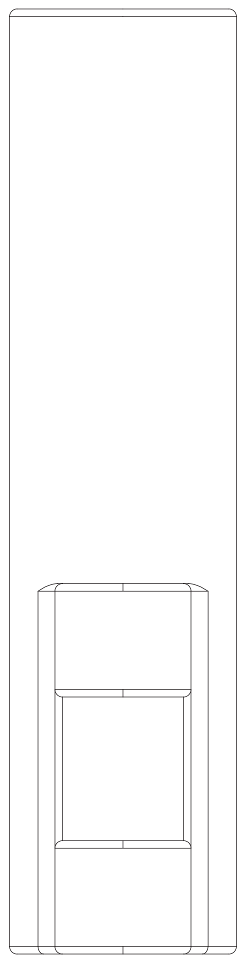
Perspective



Top

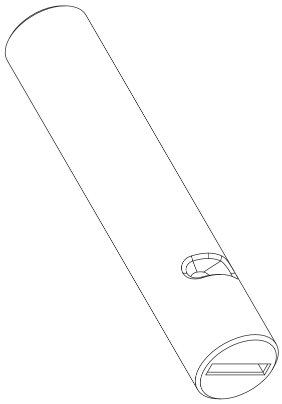


Side

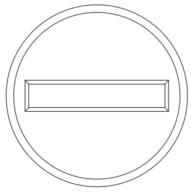


Front

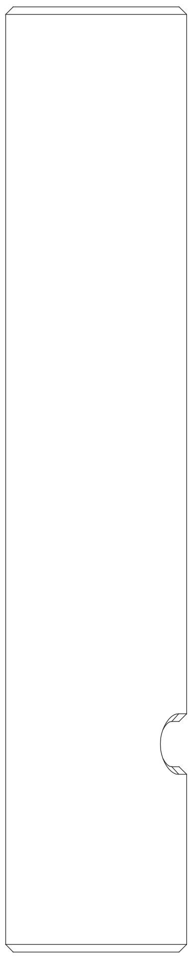
Part name: Mirror arm - core	Scale: 1 : 1	Process/Material: 3D print - ABS



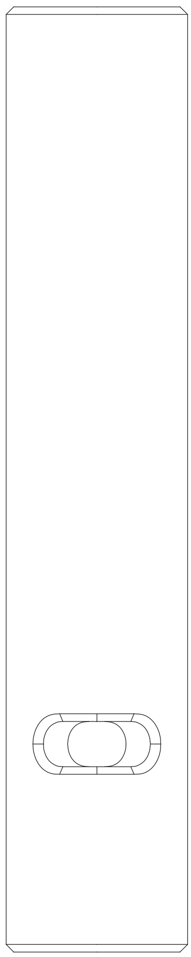
Perspective



Top

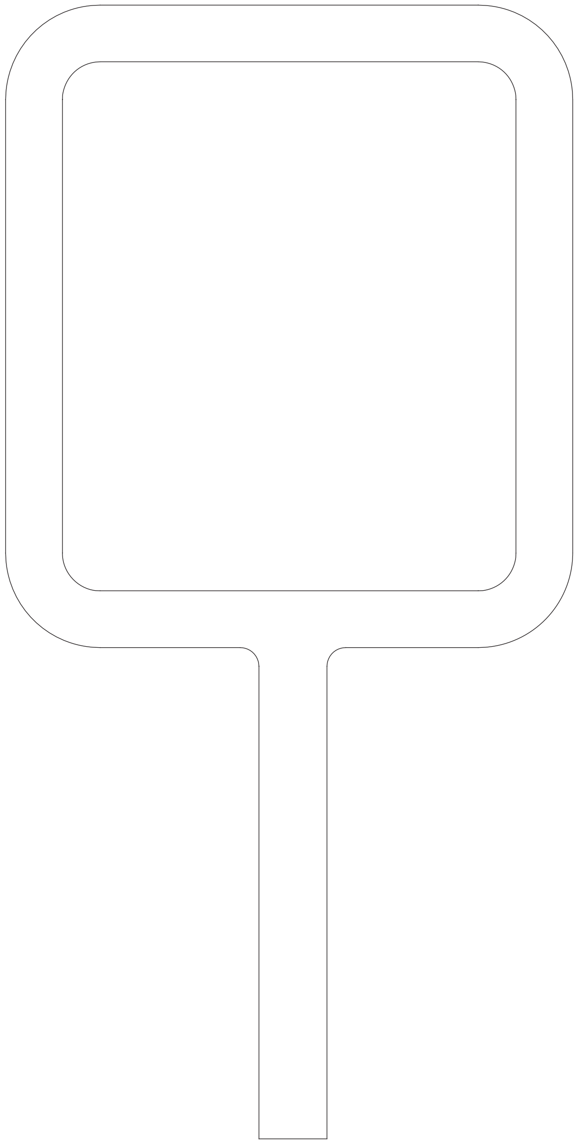


Side



Front

Part name: Mirror arm - half-mirror display (150 x 170)	Scale: 1 : 2	Process/Material: Lasercut - acrylic



Top

A.2 Second prototype

This section contains the drawings for the second prototype.

1. Camera holder (35 deg)
2. Lens array

    Lens holder

    Lens holder - Fresnel lens

    Lens holder - bottom plate

    Lens holder - top plate

    Lens holder - mid plate

    Arm

    Base - main

    Base - bottom plate

    Base - mid plate

    Base - top plate

    Base - top insert

3. Projector case

    Core - top/bottom plate

    Core - side plate

    Case - side plate

    Case - bottom plate

    Case - front/back lower plate

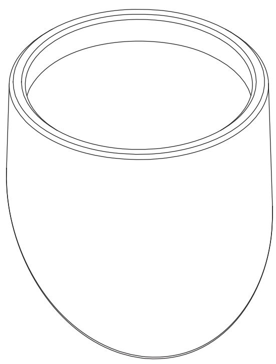
    Case - front upper plate

    Case - back upper plate

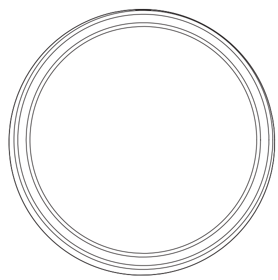
4. Mirror arm

    Half-mirror display (200 $\times$ 200)

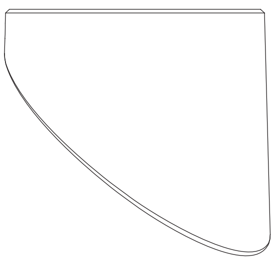
Part name: Camera holder (35 deg)	Scale: 1 : 1	Process/Material: 3D print - ABS



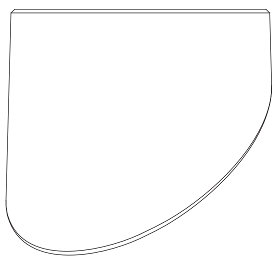
Perspective



Top

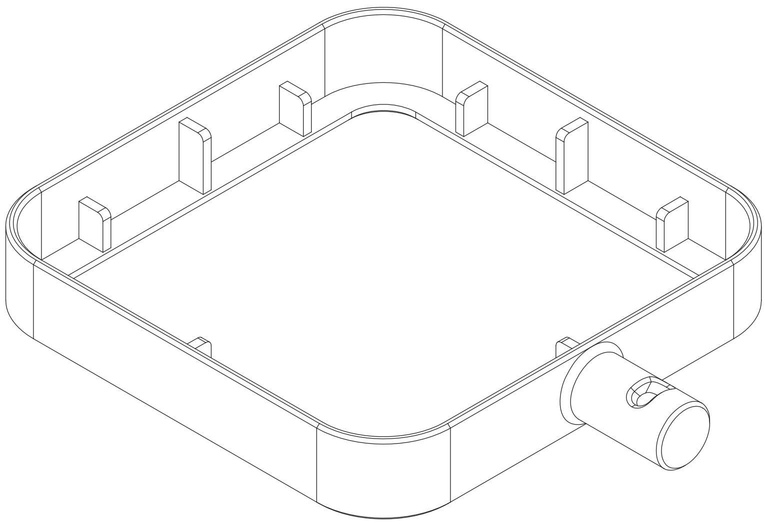


Side

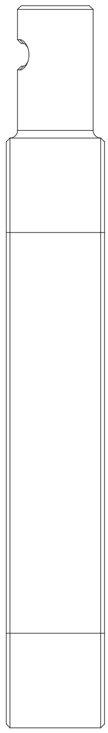


Front

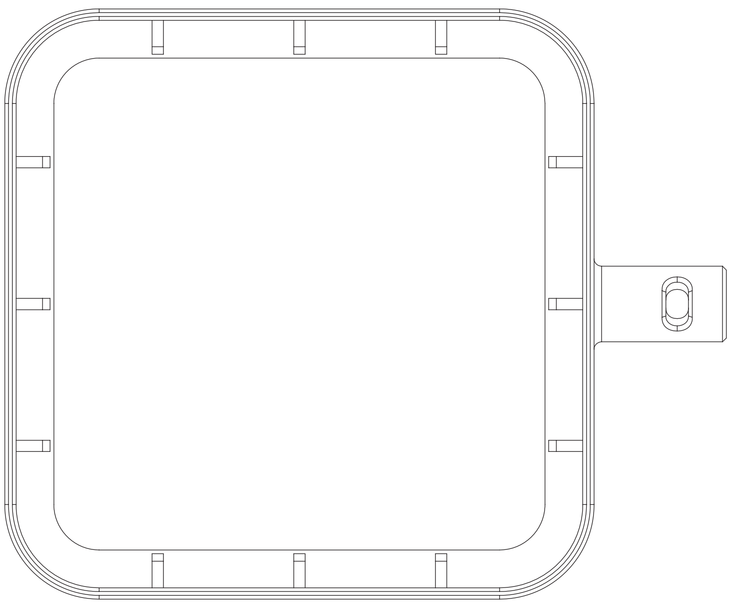
Part name: Lens array - lens holder	Scale: 1 : 2	Process/Material: 3D print - ABS



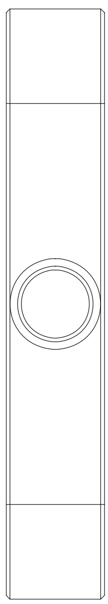
Perspective



Side

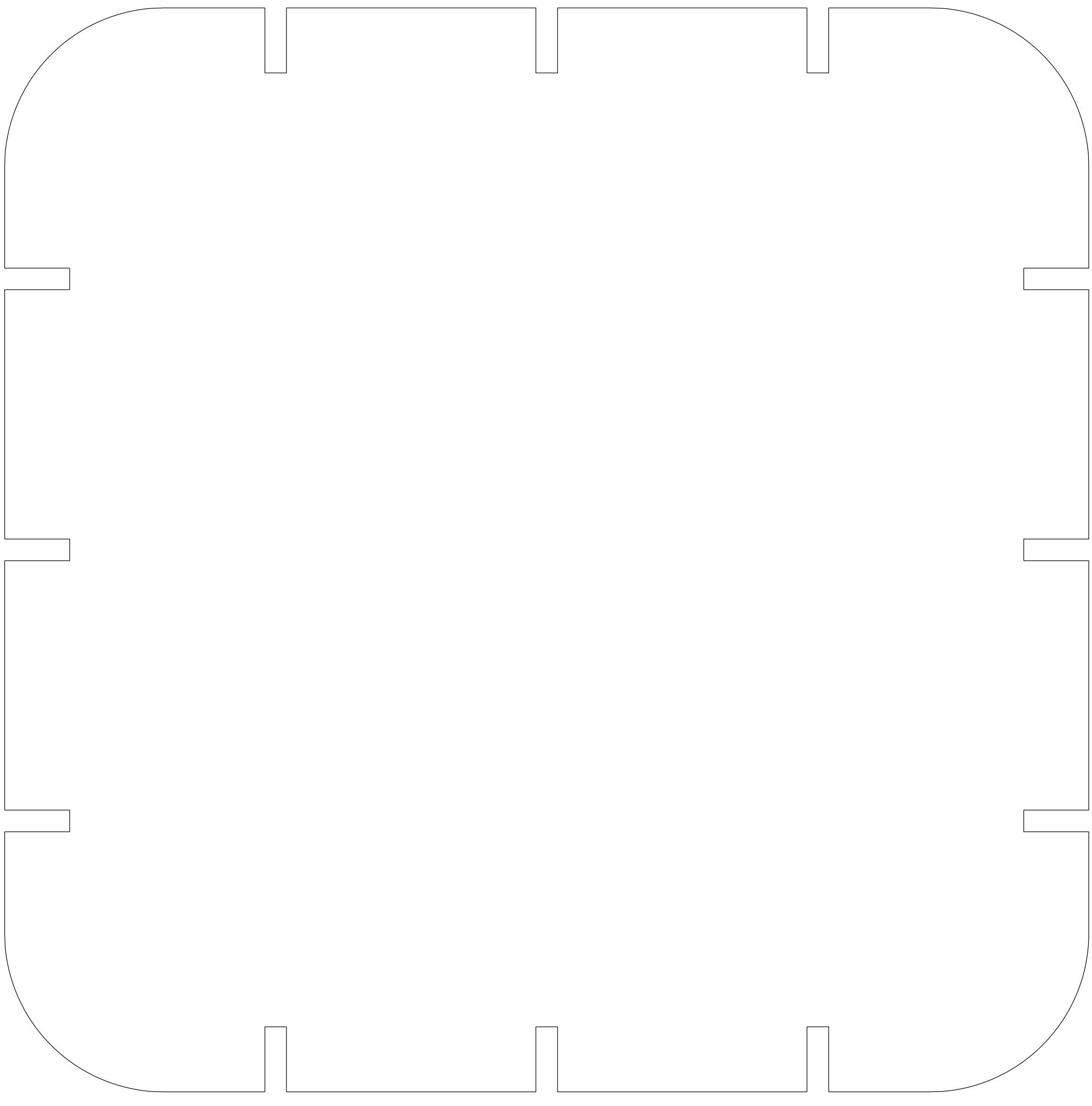


Front



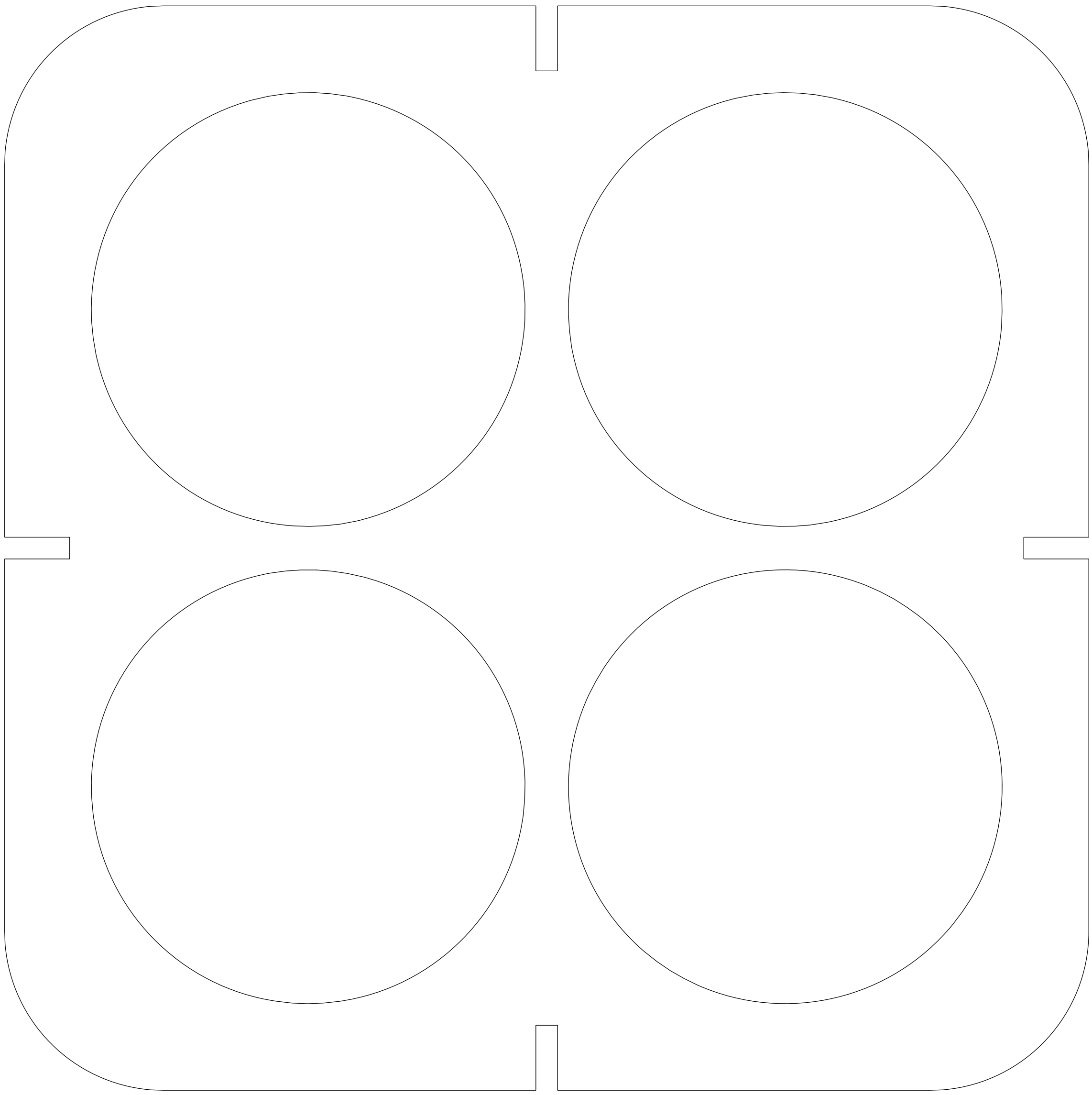
Bottom

Part name: Lens array - lens holder - fresnel lens	Scale: 1 : 1	Process/Material: Lasercut - acrylic



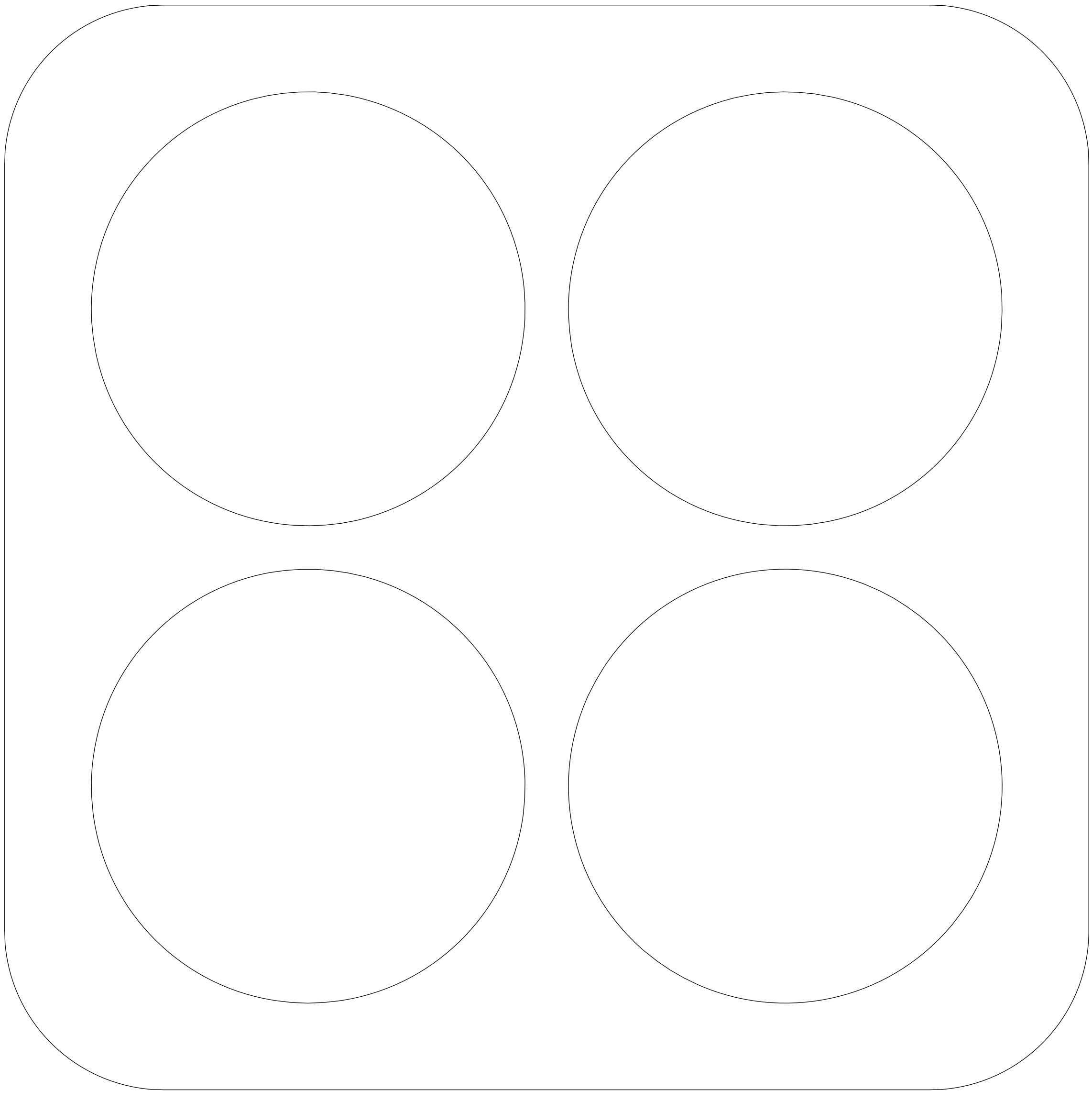
Top

Part name: Lens array - lens holder - bottom plate	Scale: 1 : 1	Process/Material: Lasercut - acrylic



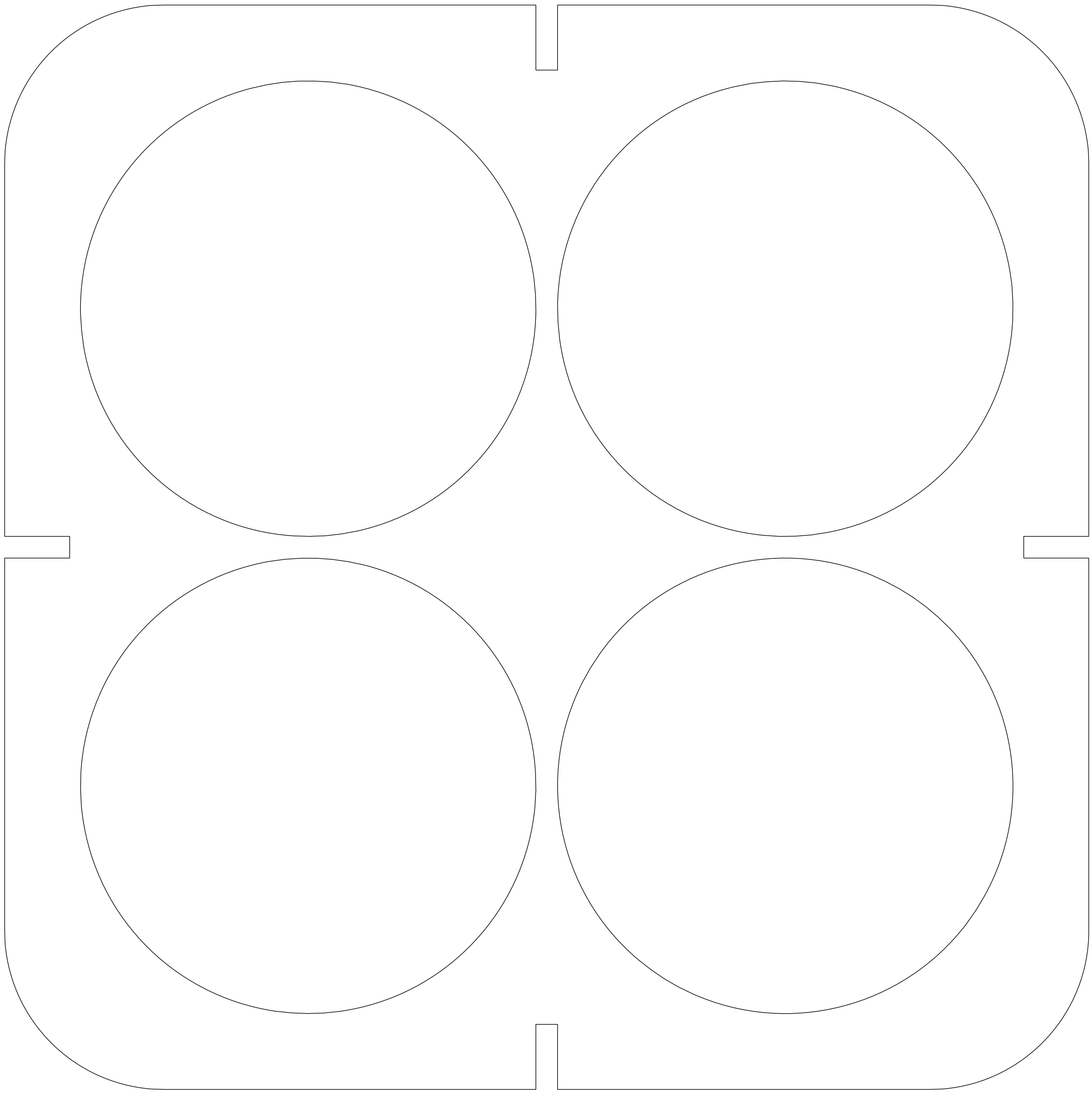
Top

Part name: Lens array - lens holder - top plate	Scale: 1 : 1	Process/Material: Lasercut - acrylic



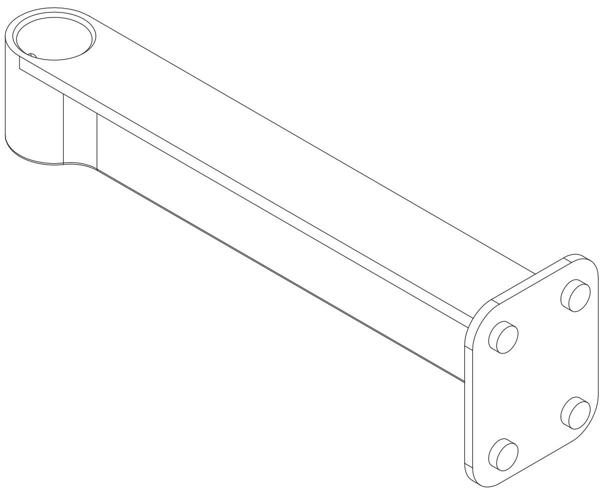
Top

Part name: Lens holder - mid plate	Scale: 1 : 1	Process/Material: Lasercut - acrylic

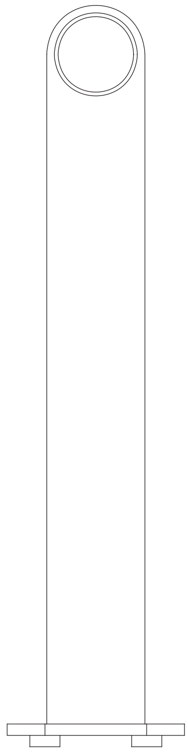


Top

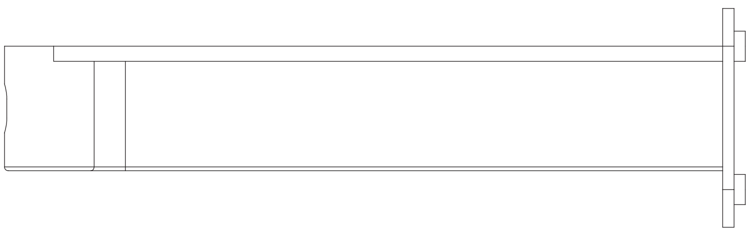
Part name: Lens array - arm	Scale: 1 : 2	Process/Material: 3D print - ABS



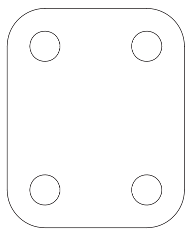
Perspective



Front

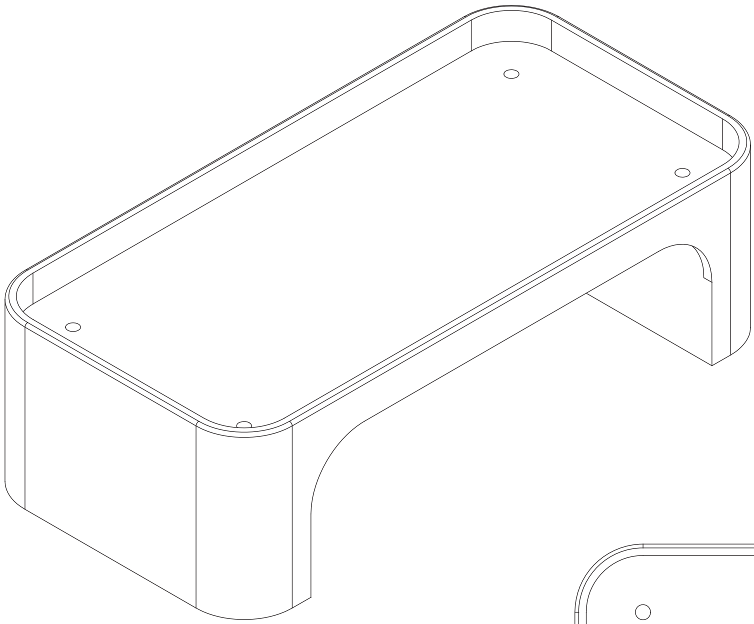


Side

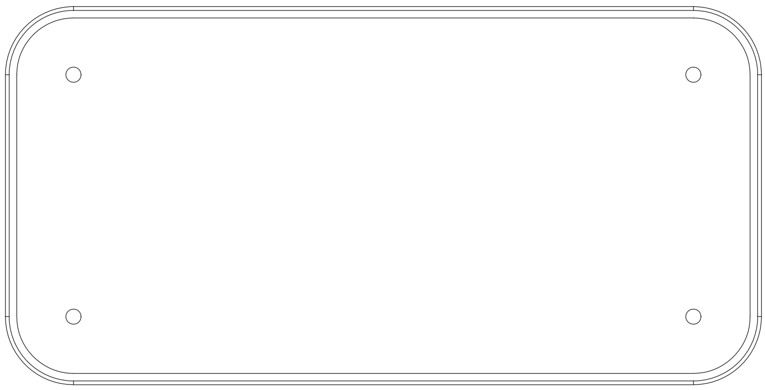


Bottom

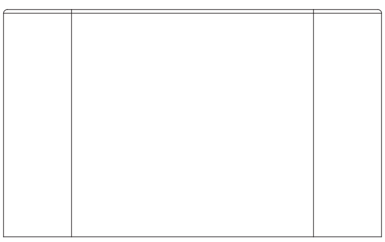
Part name: Lens array - base - main	Scale: 1 : 2	Process/Material: 3D print - ABS



Perspective



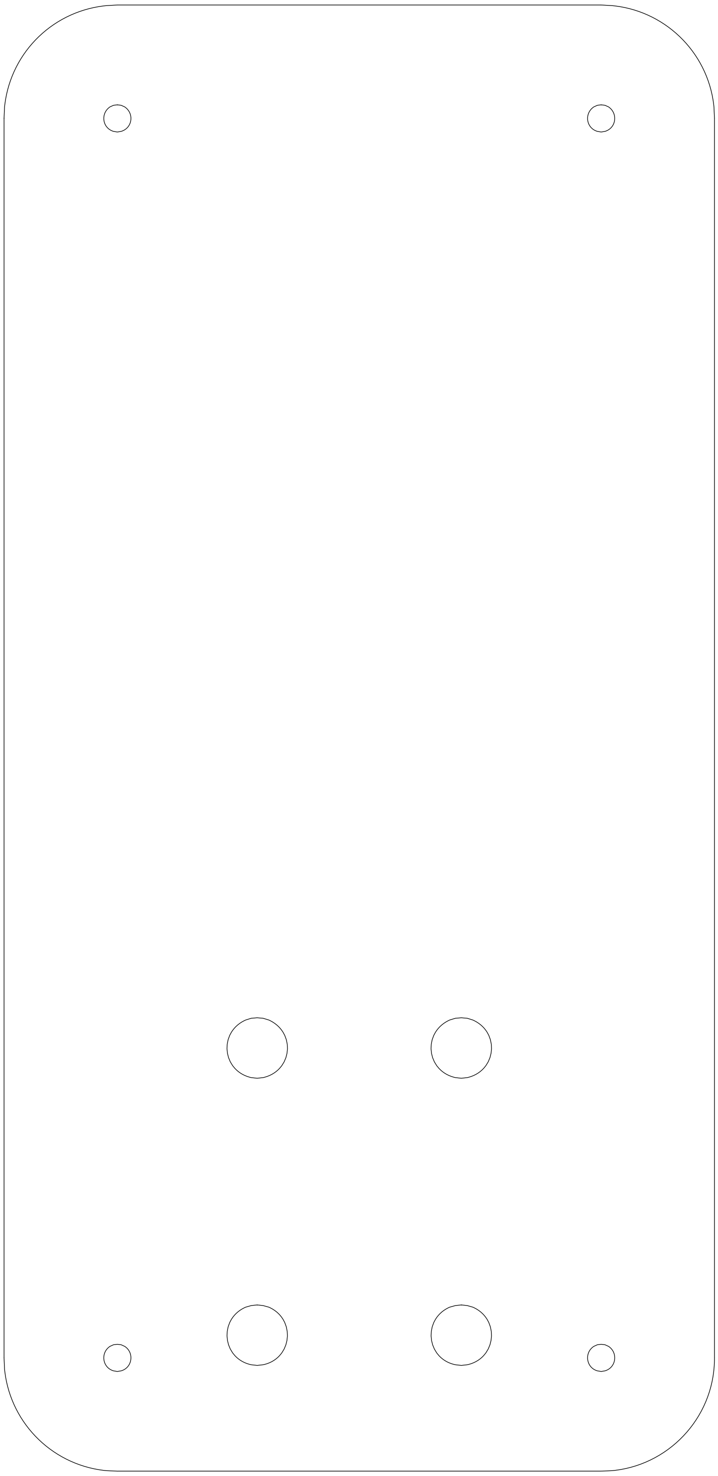
Top



Side

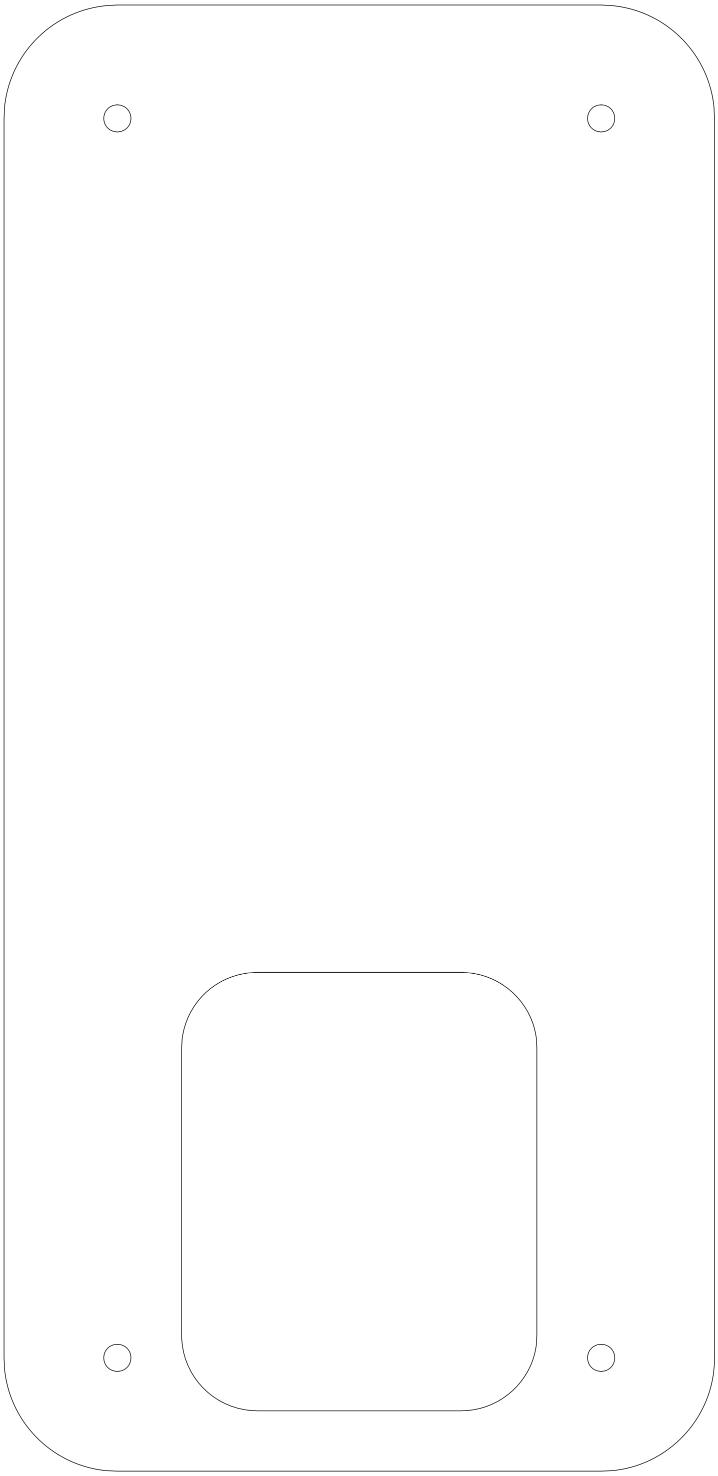
Front

Part name: Lens array - base - bottom plate	Scale: 1 : 1	Process/Material: Lasercut - acrylic



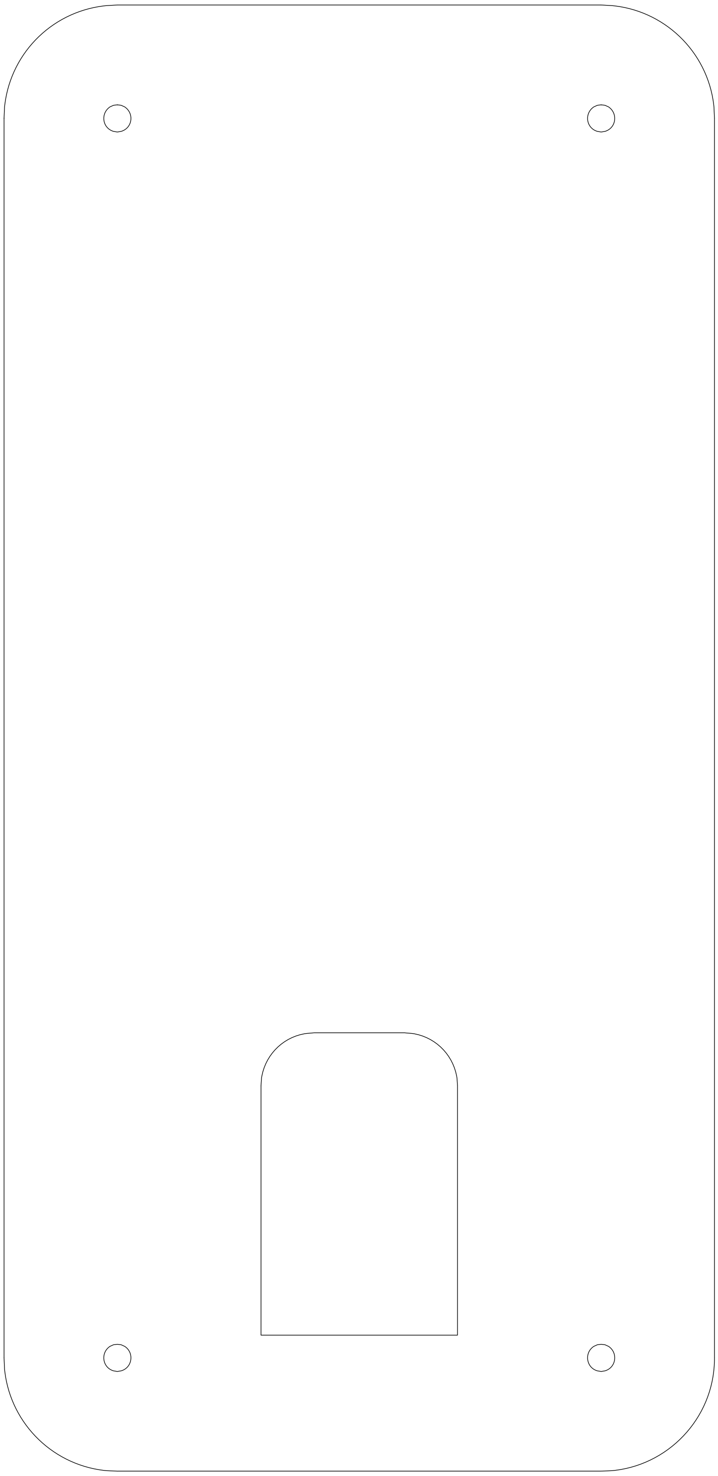
Top

Part name: Lens array - base - mid plate	Scale: 1 : 1	Process/Material: Lasercut - acrylic



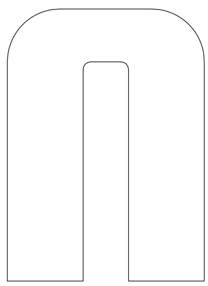
Top

Part name: Lens array - base - top plate	Scale: 1 : 1	Process/Material: Lasercut - acrylic



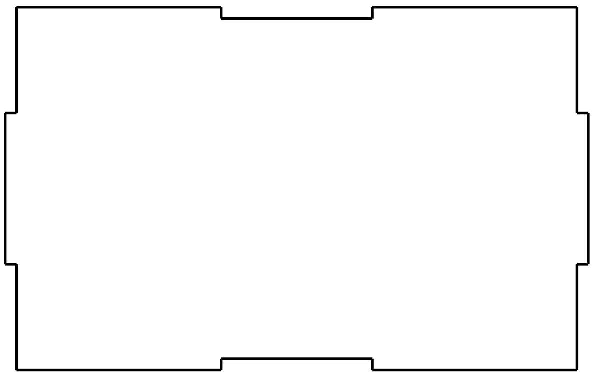
Top

Part name: Lens array - base - top insert	Scale: 1 : 1	Process/Material: Lasercut - acrylic



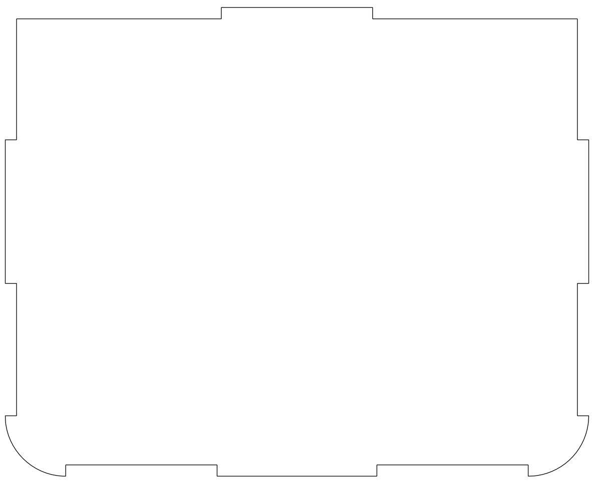
Top

Part name: Projector case - core - top/bottom plate	Scale: 1 : 2	Process/Material: Lasercut - acrylic



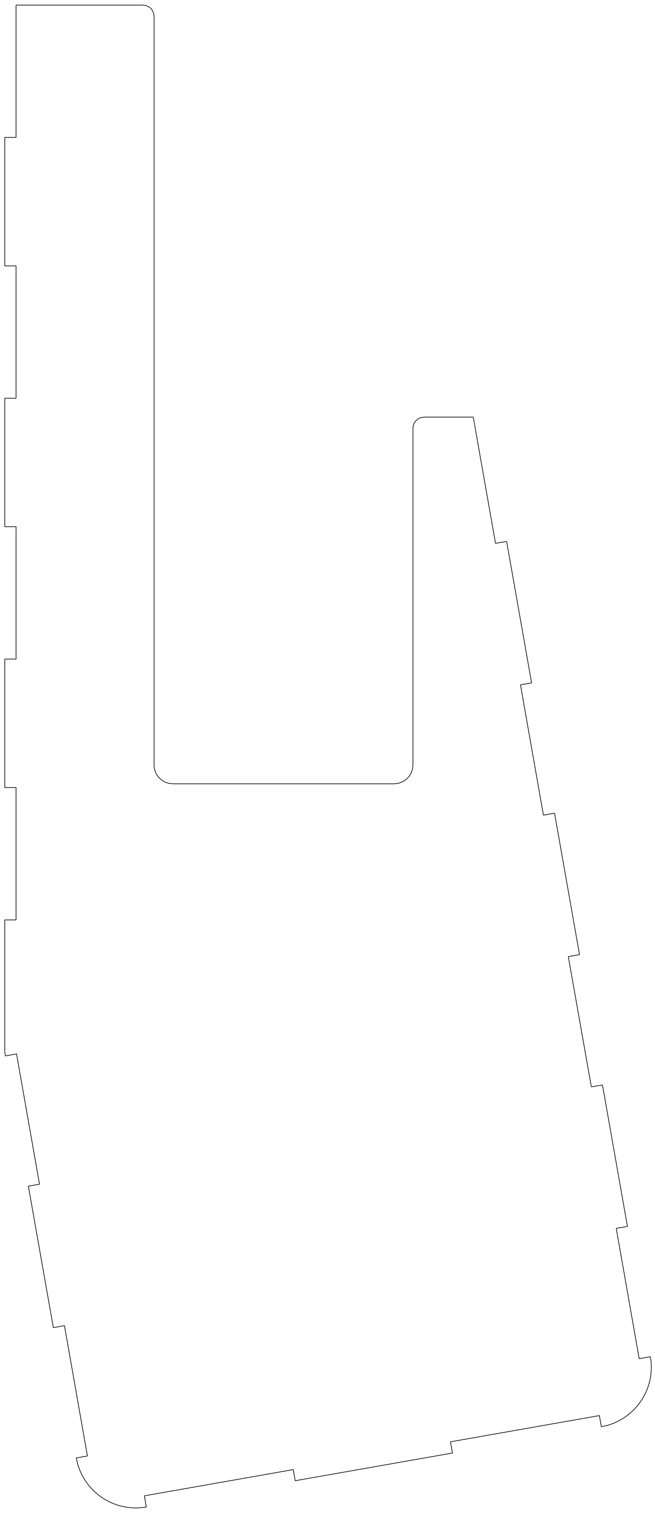
Top

Part name: Projector case - core - side plate	Scale: 1 : 2	Process/Material: Lasercut - acrylic



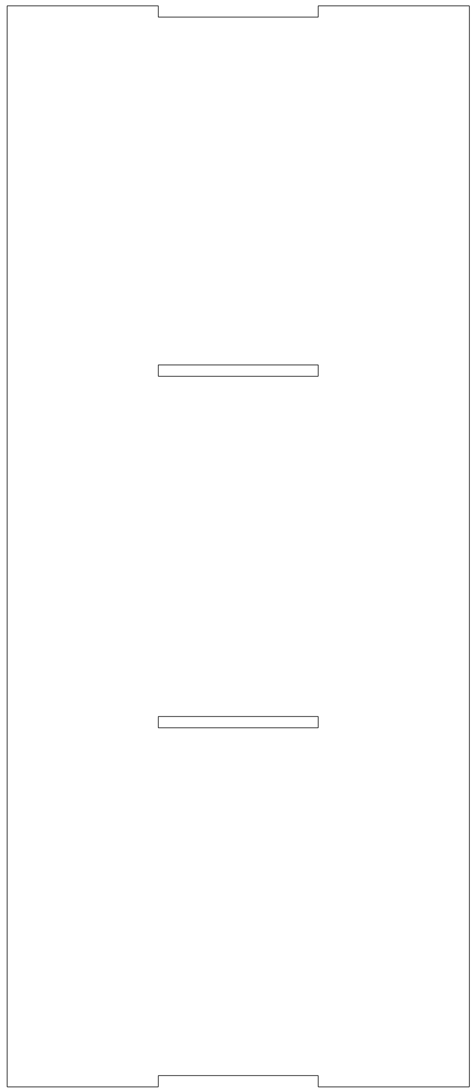
Top

Part name: Projector case - case - side plate	Scale: 1 : 2	Process/Material: Lasercut - acrylic



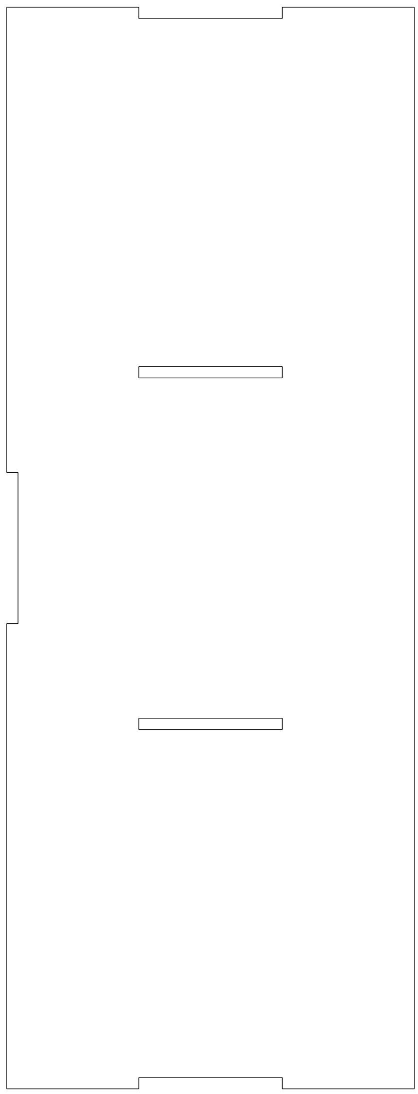
Top

Part name: Projector case - case - bottom plate	Scale: 1 : 2	Process/Material: Lasercut - acrylic



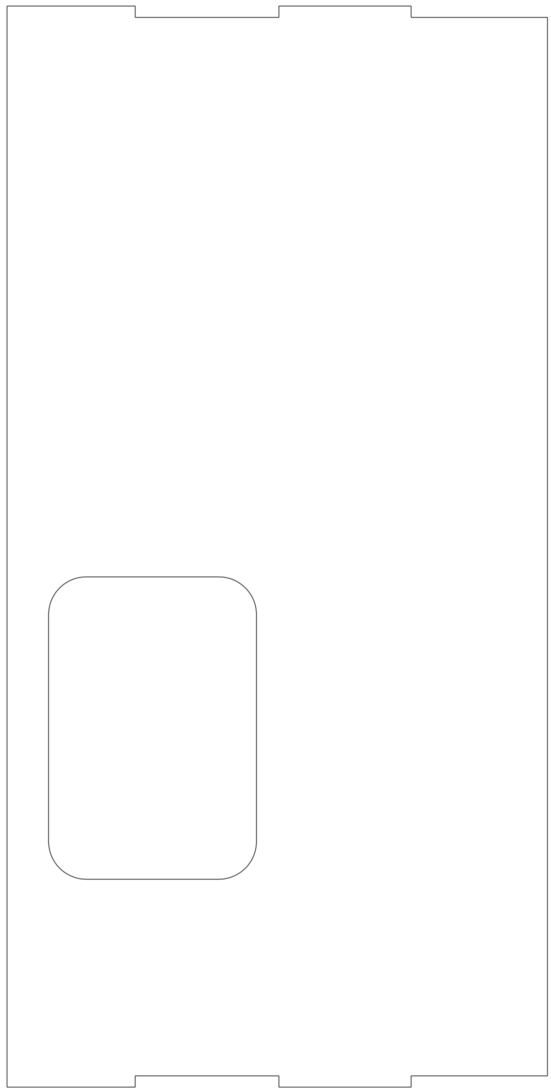
Top

Part name: Projector case - case - front/back lower plate	Scale: 1 : 2	Process/Material: Lasercut - acrylic



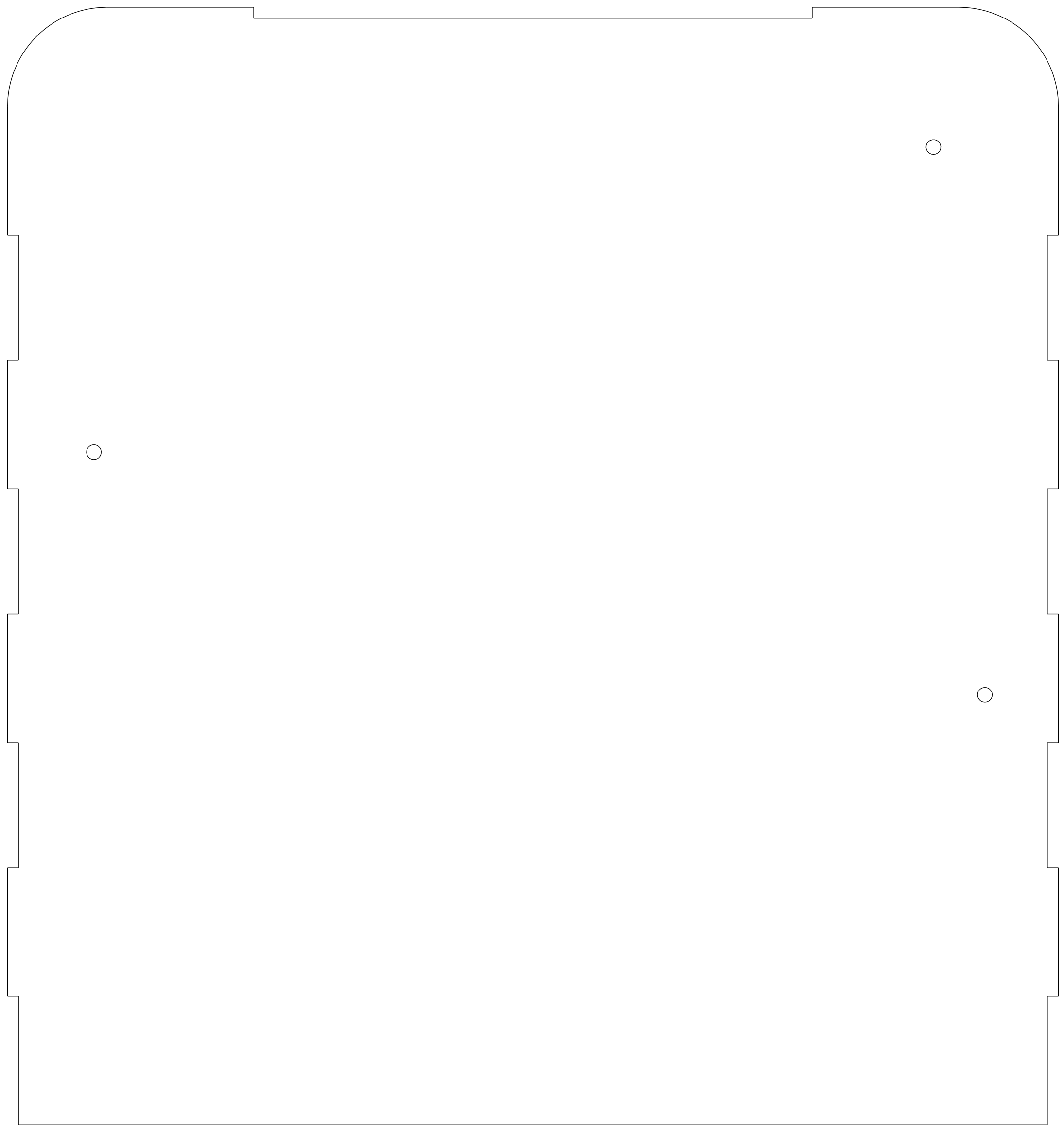
Top

Part name: Projector case - case - front upper plate	Scale: 1 : 2	Process/Material: Lasercut - acrylic



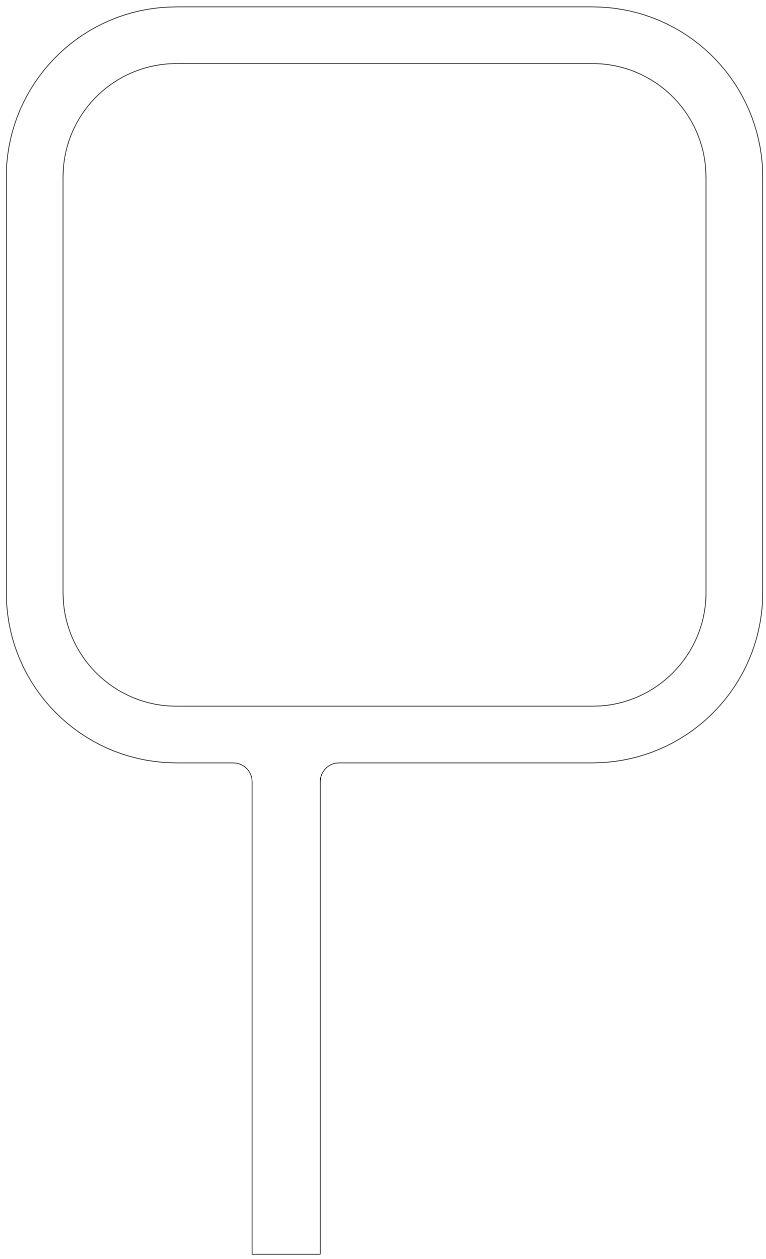
Top

Part name: Projector case - case - back upper plate	Scale: 1 : 2	Process/Material: Lasercut - acrylic



Top

Part name: Mirror arm - half-mirror display (200 x 200)	Scale: 1 : 2	Process/Material: Lasercut - acrylic



Top

A.3 Third prototype

This section contains the drawings for the third prototype.

1. Mirror arm

   Arm - new

   Core - new

   Half-mirror display (200 × 240)

2. Projector case

   Body

   Body - base plate

   Top bezel

3. Harness & belt

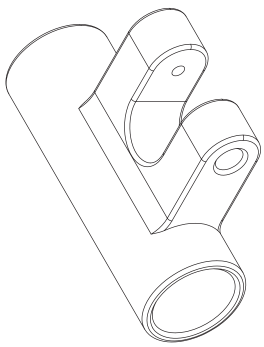
   Harness attachment - top plate

   Harness attachment - bottom plate

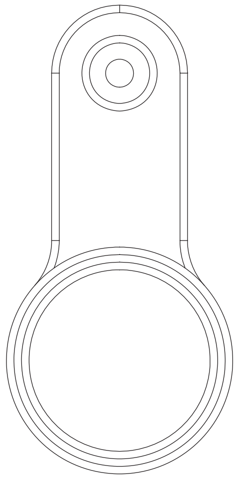
   Harness canvas

   Belt clip

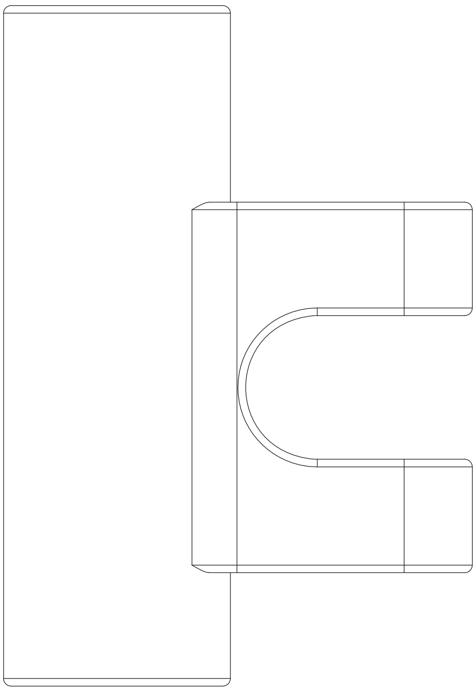
Part name: Mirror arm - arm - new	Scale: 1 : 1	Process/Material: 3D print - ABS



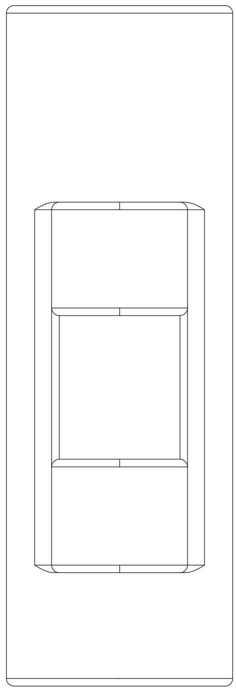
Perspective



Top

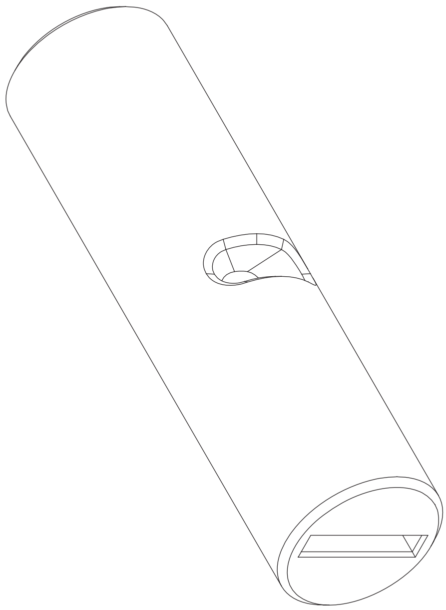


Side

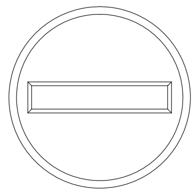


Front

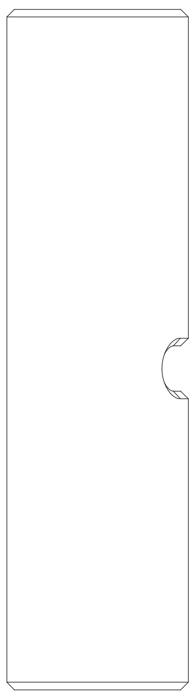
Part name: Mirror arm - core - new	Scale: 1 : 1	Process/Material: 3D print - ABS



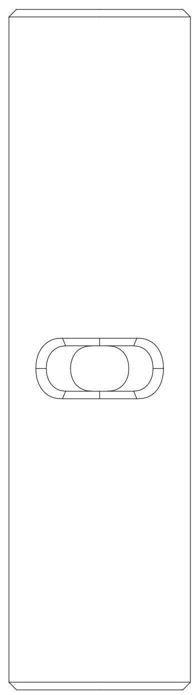
Perspective



Top

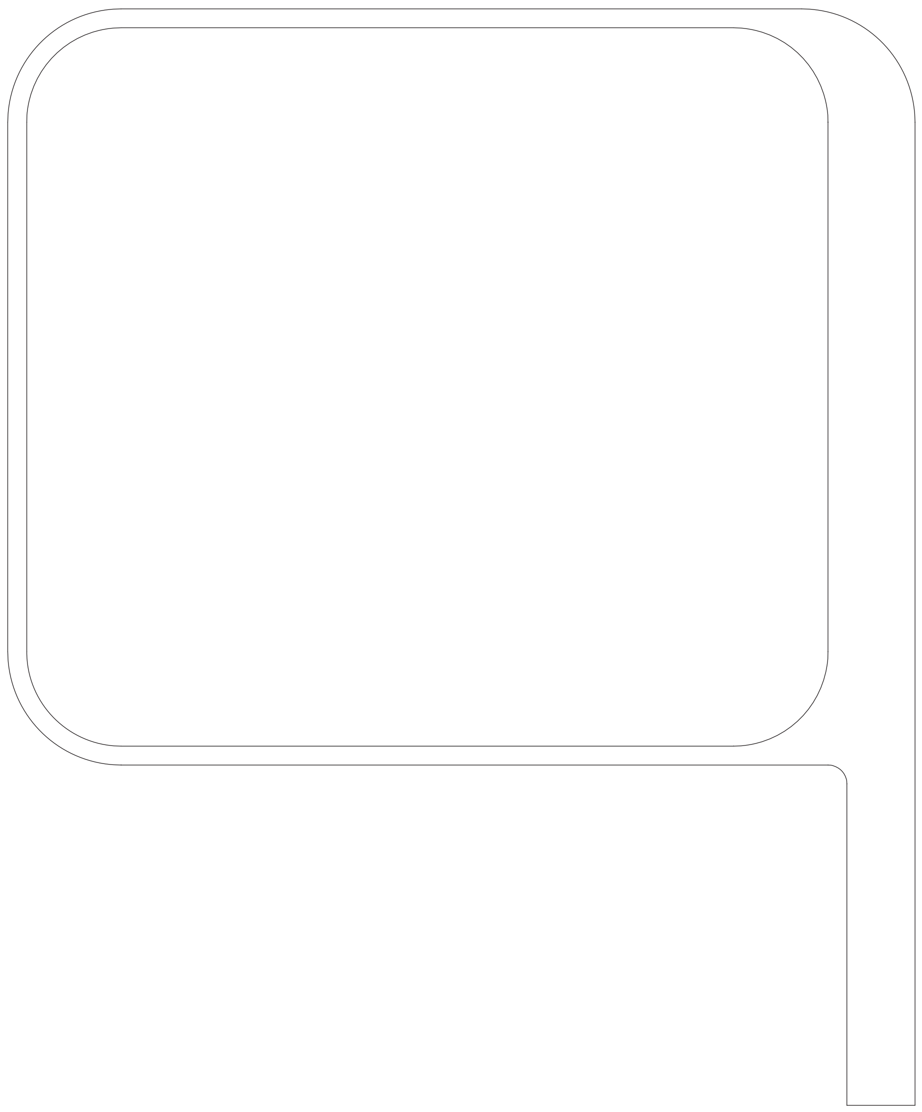


Side



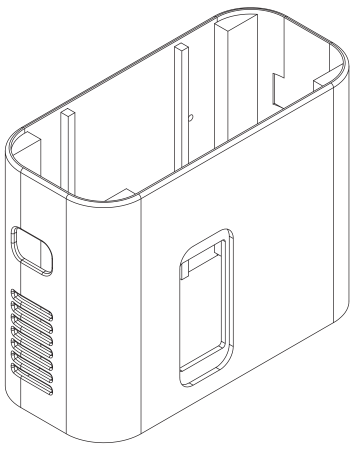
Front

Part name: Mirror arm - half-mirror display (200 x 240)	Scale: 1 : 2	Process/Material: Lasercut - acrylic

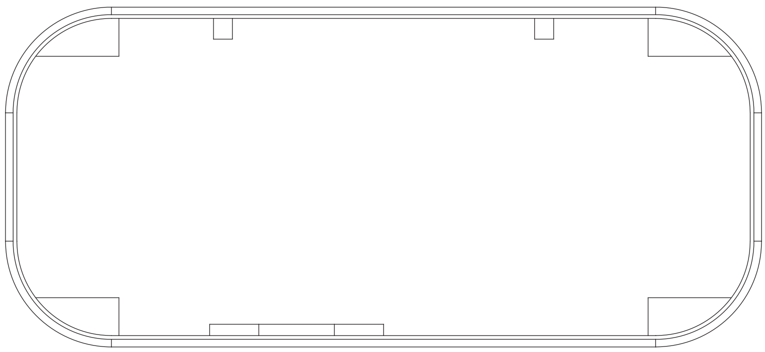


Top

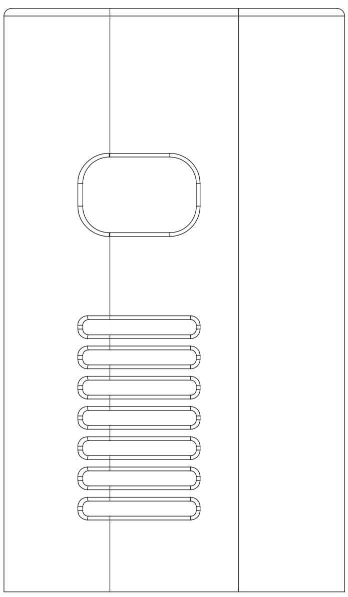
Part name: Projector case - body	Scale: 1 : 2	Process/Material: 3D print - ABS



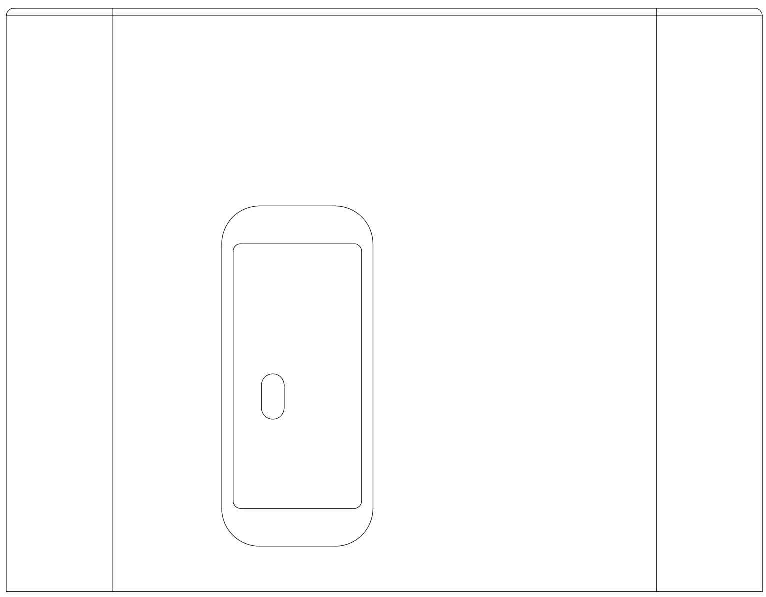
Perspective



Top

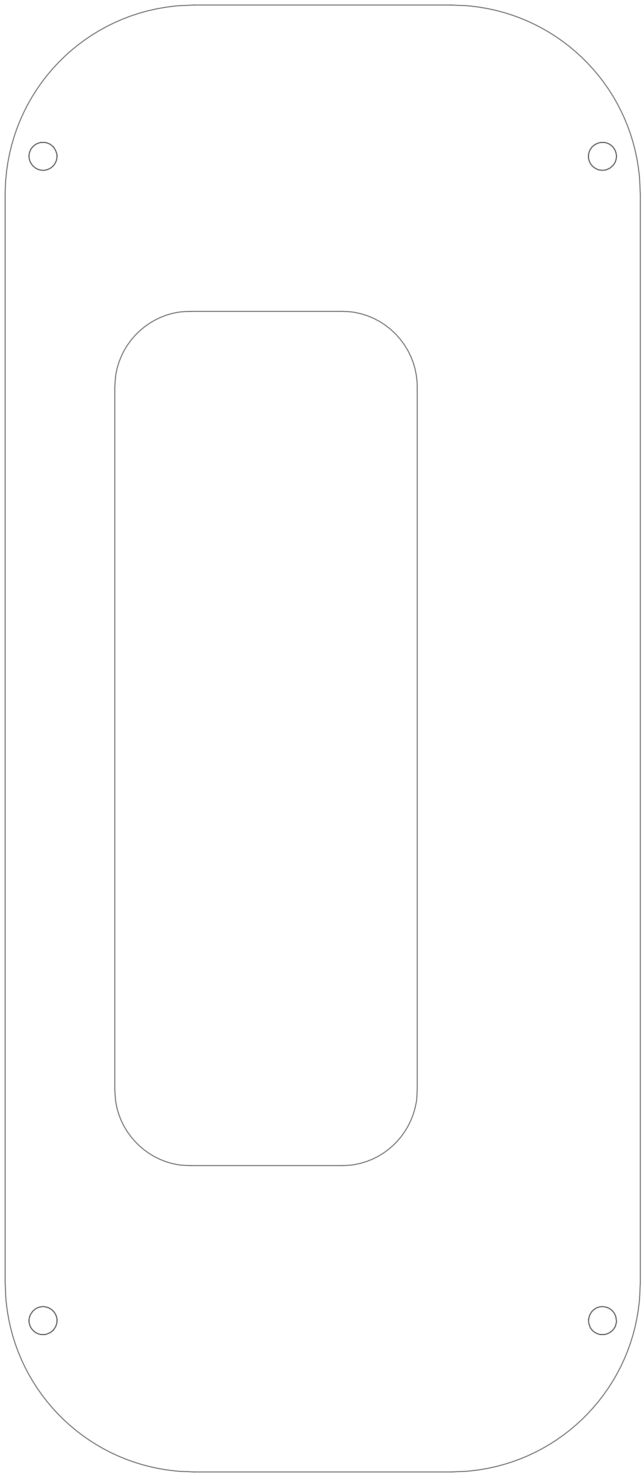


Side



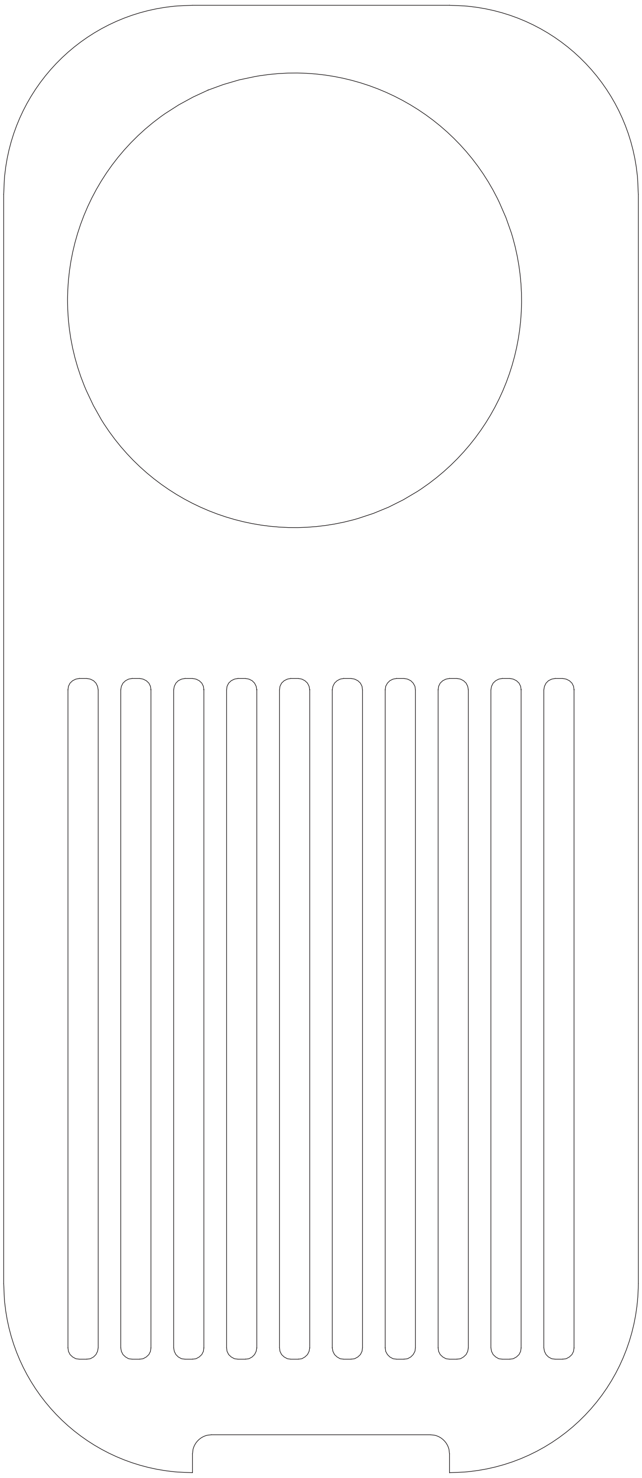
Front

Part name: Projector case - body - base plate	Scale: 1 : 1	Process/Material: Lasercut - acrylic



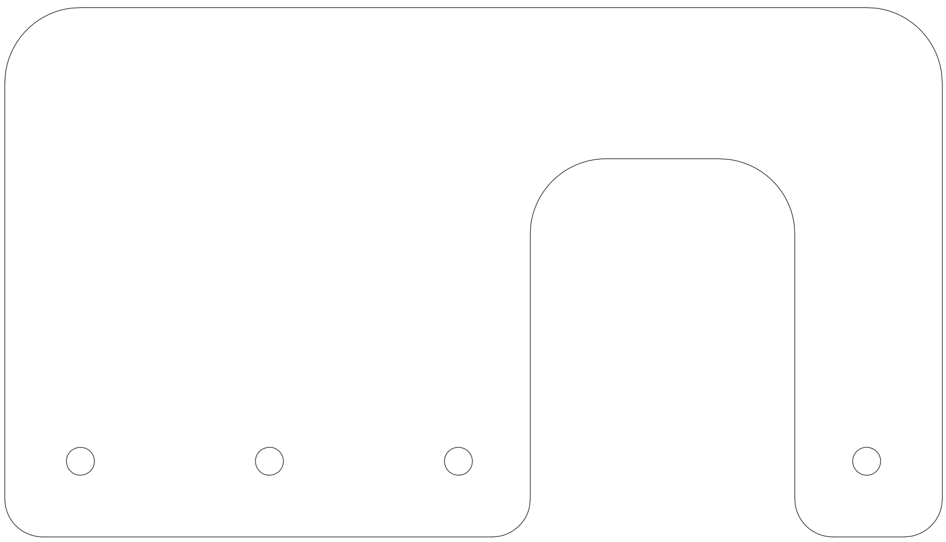
Top

Part name: Projector case - top bezel	Scale: 1 : 1	Process/Material: Lasercut - acrylic



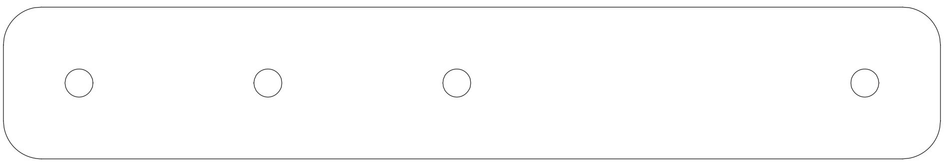
Top

Part name: Harness & belt - harness attachment - top plate	Scale: 1 : 1	Process/Material: Lasercut - acrylic



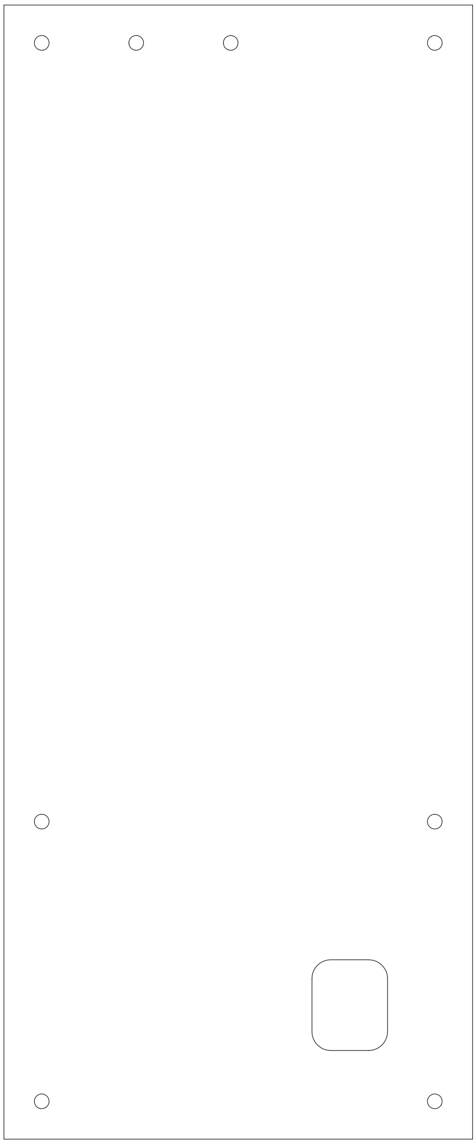
Top

Part name: Harness & belt - harness attachment - bottom plate	Scale: 1 : 1	Process/Material: Lasercut - acrylic



Top

Part name: Harness & belt - harness canvas	Scale: 1 : 2	Process/Material: Lasercut - canvas



Top

Part name: Harness & belt - harness attachment - belt clip	Scale: 1 : 1	Process/Material: Lasercut - acrylic

Top

Appendix B

Evaluation test log

This appendix contains the log for the evaluation test conducted on the 8th June 2012 at the B2 carpark in KMD. There are a total of 8 participants.

B.1 Participant 1

Participant information

Name: Calista Lee
Age: 25
Gender: Female
Height: 1.53m
Master eye: right
Driving license obtained: 2008
Driving experience: 1 times monthly for 4 year (novice)
Rearview camera monitor experience: NO

Scenario 1: No aid

See obstacles:
NO for static(doll)
YES for moving(ball) seen through the right mirror.
Observations:
Uses primarily right rearview mirror.
Uses left and interior mirrors once.
Feedback:
Difficult to judge distance.
Not sure where the back of the car is.

Scenario 2: ThroughView(TV)

Trial 1:
Rating: 6.0
See obstacles: YES
Observations:
Uses primarily TV.
Uses right rearview mirror.

Raises body to see behind the vehicle.
Feedback:
Dont know where the car ends.
Can see wider field of view in RV. Less response time to obstacles in TV.
Tiring to turn around.

Trial 2:
Rating: 6.0
See obstacles: N.A.
Observations:
uses right rearview mirror.
uses TV.
Feedback:
Cant see end of car.

Trial 3:
Rating: 6.0
See obstacles: YES
Observations:
Uses right rearview mirror.
Uses TV.
Feedback:
Getting used to it.
Too narrow field of view.
Too sudden, rolling ball entering the view.

Trial 4:
Rating: 6.0
See obstacles: YES
Observations:
Uses the right rearview mirror.
Uses TV.
Looks above half-mirror to see behind.
Feedback:
Uncomfortable to keep looking back.

Trial 5:
Rating: 6.0
See obstacles: NO
Observations:
Uses right rearview mirror.
Uses TV.

Looks above half-mirror to see behind.
Feedback:
Neck pain.

Overall feedback: None.

Scenario 3: Rearview camera monitor(RV)

Trial 1:
Rating: 7.0
See obstacles: N.A.
Observations:
Uses primarily RV.
Uses right mirror.
Does not know what the frame means.
Feedback:
Easier than no aid.
Not sure where the end of the car is.

Trial 2:
Rating: 8.0
See obstacles: YES
Observations:
Uses primarily the RV.
Uses the right mirror occasionally.
Feedback:
Beginning to figure things out.

Trial 3:
Rating: 8.0
See obstacles: N.A.
Observations:
Uses primarily the RV.
Uses the right mirror occasionally.
Feedback:
Getting used to the system.

Trial 4:
Rating: 8.0
See obstacles: YES
Observations:
Uses primarily the RV.

Uses the right rearview mirror occasionally.
Feedback:
Doesnt look at the interior rearview mirror anymore.

Trial 5:
Rating: 7.0
See obstacles: YES
Observations:
Uses primarily the RV.
Uses the right rearview mirror occasionally.
Feedback:
Cannot see the side of the car in RV.

Overall feedback:
Helpful because can see what is behind the car.

Scenario 4: Both systems

ThroughView rating: 7.0
Rearview rating: 8.0
See obstacles: YES
Observations:
Uses RV and TV.
Uses right mirror occasionally.

Overall feedback:
still prefer RV over TV.
RV is good for wider view.
TV is good for close up.
RV is not good for identifying obstacles on the ground.
feels that both works in tandem.
feels that the visual information provided by TV can be put in RV.

B.2 Participant 2

Participant information

Name: Enki Li
Age: 27
Gender: Female
Height: 1.73m
Master eye: left
Driving license obtained: 2003
Driving experience: 4 times weekly for 3 year (expert)
Rearview camera monitor experience: NO

Scenario 1: No aid

See obstacles: NO
Observations:
Looks back most of the time.
Feedback:
Difficult to see through the half-mirror display when looking back because it darkens the view.

Scenario 2: ThroughView(TV)

Trial 1:
Rating: 6.0
See obstacles: YES
Observations:
Uses primarily TV.
Raises head above the half-mirror display to see behind.
Feedback:
Narrow field of view.
Tilted display.
Colour is not right.

Trial 2:
Rating: 6.5
See obstacles: N.A.
Observations:
uses TV.
Feedback:
Can feel a sense of invisibility. Can see through the car.

Trial 3:

Rating: 6.0
See obstacles: YES
Observations:
Uses TV.
Feedback:
Too narrow field of view.
Can only see the rolling ball when it is directly behind the car.

Trial 4:
Rating: 6.0
See obstacles: YES
Observations:
Uses TV.
Looks above half-mirror to see behind.
Feedback:
Good that the rear view can be seen while looking back.
Contrast too low. Cant tell objects clearly.

Trial 5:
Rating: 6.5
See obstacles: NO
Observations:
Uses right rearview mirror.
Uses TV.
Looks above half-mirror to see behind.
Feedback:
Not enough visual information compared to RV.

Overall feedback: None.

Scenario 3: Rearview camera monitor(RV)

Trial 1:
Rating: 7.0
See obstacles: N.A.
Observations:
Uses primarily RV.
Uses right mirror.
Feedback:
helpful.
cant judge distance.
mental rotation problem.

Trial 2:
Rating: 8.0
See obstacles: YES
Observations:
Uses primarily the RV.
Leans forward to look closer at the screen when an obstacle is seen.
Looks back to confirm parking.
User feedback:
Can see that there is an obstacle but cant tell what it is.

Trial 3:
Rating: 8.0
See obstacles: N.A.
Observations:
Uses primarily the RV.
Feedback:
Can rely on system but afraid of mental rotation.

Trial 4:
Rating: 8.0
See obstacles: YES
Observations:
Uses primarily the RV.
Feedback:
Black border around an object is helpful.

Trial 5:
Rating: 7.5
See obstacles: YES
Observations:
- Uses primarily the RV.
Feedback:
Beginning to be less sensitive to objects on the screen.
Can see the rolling ball but does not see the black border around it.

Overall feedback:
If the computer is broken, RV would not work.

Scenario 4: Both systems

ThroughView rating: 6.5
Rearview rating: 7.5
See obstacles: YES
Observations:
Uses RV and TV.
Uses TV to confirm obstacles.

Overall feedback:
able to see a clearer and wider view with RV.
distance perception is better with TV.
TV is good for reversing.
RV is more convenient and less tiring but turning back to look is essential to be a good driver.

B.3 Participant 3

Participant information

Name: Hiroki Matsuyama
Age: 23
Gender: Male
Height: 1.75m
Master eye: Right
Driving license obtained: 2007
Driving experience: hardly. 1 times every two months.
Rearview camera monitor experience: YES

Scenario 1: No aid

See obstacles: NO
Observations:
used the back mirror only
Feedback:
couldnt see anything

Scenario 2: ThroughView(TV)

Trial 1:
Rating: 5.0
See obstacles: NO
Observations:
used the system wrong way. tried to use TV through the back mirror
Feedback:
couldnt see anything

Trial 2:
Rating: 8.0
See obstacles: N.A.
Observations:
successfully used the TV.
looked at the back mirror quickly while using the TV
Feedback:
realized how use the system.

Trial 3:
Rating: 8.0
See obstacles: YES
Observations:

used the TV and back mirror and (near) side mirror
Feedback:
could see something white, but not sure if it was a soccer ball or just ball.

Trial 4:
Rating: 8.0
See obstacles: YES
Observations:
used the TV and then found the obstacle.
also used far side mirror
Feedback:
know how to use the TV better than before

Trial 5:
Rating: 8.0
See obstacles: NO
Observations:
used TV and far side mirror.
Feedback:
same. without any object, hard to judge.

Overall feedback:
because he normally uses both the back mirror and real view and feels enough, looking back is kind of too much.

Scenario 3: Rearview camera monitor(RV)

Trial 1:
Rating: 6.0
See obstacles: N.A.
Observations:
watched the back mirror and RV alternately
Feedback:
wider view is good.

Trial 2:
Rating: 6.0
See obstacles: YES
Observations:
mostly used the RV, sometimes back mirror.
Feedback: none

Trial 3:
Rating: 6.0
See obstacles: N.A.
Observations:
mostly used the RV, sometimes back mirror.
Feedback: just normal

Trial 4:
Rating: 6.0
See obstacles: YES
Observations:
mostly used the RV
Feedback: none.

Trial 5:
Rating: 6.0
See obstacles: YES
Observations:
mostly used the RV
Feedback: none.

Overall feedback:
because its hard to know the distance, he thinks combination of RV and mirror is important.

Scenario 4: Both systems

ThroughView rating: 5.0
Rearview rating: 7.0
See obstacles: YES
Observations:
mostly used RV. used TV for double check the object.

Overall feedback:
its great if the TV can be used through the back mirror.
TV is good for distance perception.
Priority- 1. mirror, 2. RV, 3. TV

B.4 Participant 4

Participant information

Name: Jennie Pao
Age: 29
Gender: Female
Height: 1.72m
Master eye: right
Driving license obtained: 1998
Driving experience: 2 times daily for 7 year (expert)
Rearview camera monitor experience: YES

Scenario 1: No aid

See obstacles: NO
Observations:
Uses right and interior rearview mirrors.
Looks back.
Feedback:
Completely unaware of objects behind the vehicle.

Scenario 2: ThroughView(TV)

Trial 1:
Rating: 6.5
See obstacles: YES
Observations:
Uses primarily TV.
Uses left hand to support chin.
Feedback:
Cannot see wide enough.
Can see obstacles clearly, able to discern.

Trial 2:
Rating: 6.5
See obstacles: N.A.
Observations:
uses right rearview mirrors.
uses TV.
looks above the half-mirror display to see behind.
Feedback:
Normally would not bother with checking the floor behind the vehicle.

Trial 3:
Rating: 7.0
See obstacles: YES
Observations:
Uses right rearview mirror.
Uses TV.
Looks above half-mirror to see behind.
Feedback:
Scared by the sudden appearance of the rolling ball.
A nice system to have.

Trial 4:
Rating: 7.25
See obstacles: YES
Observations:
Uses the right rearview mirror.
Uses TV.
Looks above half-mirror to see behind.
Feedback:
Good for checking objects, to find out what it exactly is.

Trial 5:
Rating: 7.25
See obstacles: NO
Observations:
Uses right rearview mirror.
Uses TV.
Looks above half-mirror to see behind.
Feedback: None.

Overall feedback:
Field of view can be wider.
The visual information provided by TV can also be displayed on the RV.

Scenario 3: Rearview camera monitor(RV)

Trial 1:
Rating: 7.0
See obstacles: N.A.
Observations:
Uses RV and right rearview mirror.
Looks back occasionally, especially to confirm parking.

Feedback:
Comfortable to look at, but can be improved.

Trial 2:
Rating: 8.0
See obstacles: YES
Observations:
Uses primarily the RV.
Uses the right and rearview mirror occasionally.
Looks back to confirm parking.
Feedback:
After discovering the obstacles at the back of the car, would get down to confirm the obstacle.
Does not believe the distances as seen from RV.

Trial 3:
Rating: 8.0
See obstacles: N.A.
Observations:
Uses primarily the RV.
Uses the right and rearview mirror occasionally.
Looks back to confirm parking.
Looks closer at screen to see obstacles.
Feedback: None.

Trial 4:
Rating: 8.0
See obstacles: YES
Observations:
Uses primarily the RV.
Uses the right and interior rearview mirror occasionally.
Feedback: None.

Trial 5:
Rating: 8.0
See obstacles: YES
Observations:
Uses primarily the RV.
Uses the right rearview mirror occasionally.
Looks back to confirm parking.
Feedback: None.

Overall feedback:
Necessary tool, only if there are low obstacles.

Scenario 4: Both systems

ThroughView rating: 7.0
Rearview rating: 8.0
See obstacles: YES
Observations:
Uses RV and TV.
Uses right mirror occasionally.

Overall feedback:
RV is still better because it provides a wider field of view and objects can be clearly seen.
TV should have a wider field of view.

B.5 Participant 5

Participant information

Name: Kevin Fan
Age: 24
Gender: Male
Height: 1.67m
Master eye: right
Driving license obtained: 2007
Driving experience: 3 times weekly for 3 year (expert)
Rearview camera monitor experience: NO

Scenario 1: No aid

See obstacles:
NO for static(doll)
YES for moving(ball) seen through the right mirror.
Observations:
Uses primarily the right rearview mirror.
Sometimes uses interior rearview mirror.
Looks back occasionally.
Feedback:
Surprised by the moving ball.
Could not see if the ball has passed.

Scenario 2: ThroughView(TV)

Trial 1:
Rating: 7.0
See obstacles: YES
Observations:
Uses a combination of TV and rearview mirrors(right and interior).
Feedback:
Saw static obstacle but did not stop because he recognized it as a doll.
Used TV to confirm obstacle.

Trial 2:
Rating: 7.0
See obstacles: N.A.
Observations:
uses the interior and right rearview mirrors.
uses TV.
Feedback:

Uses TV to check for obstacles in the distance.
Then uses the mirrors.

Trial 3:
Rating: 8.0
See obstacles: YES
Observations:
Uses the interior and right rearview mirrors.
Uses TV.
Feedback:
Appreciates the system when obstacles appear in the backing lane.
A nice system to have.

Trial 4:
Rating: 8.0
See obstacles: YES
Observations:
Uses the interior and right rearview mirrors.
Uses TV.
Feedback: None

Trial 5:
Rating: 8.0
See obstacles: NO
Observations:
Uses the interior and right rearview mirrors.
Uses TV.
Feedback: None.

Overall feedback:
System is good when you know there is something behind the vehicle.
A wider field of view is desirable.
Current implementation is too narrow.

Scenario 3: Rearview camera monitor(RV)

Trial 1:
Rating: 8.0
See obstacles: N.A.
Observations:
Uses RV and right rearview mirror.
Looks back to confirm final parking.

Feedback:
Clear image.
Wide field of view.

Trial 2:
Rating: 8.5
See obstacles: YES
Observations:
Uses primarily the RV.
Uses the right and interior rearview mirror occasionally.
Uses the left mirror once.
Feedback:
Wider field of view than TV.
Easy to see obstacles.

Trial 3:
Rating: 9.0
See obstacles: N.A.
Observations:
Uses primarily the RV.
Uses the right and interior rearview mirror occasionally.
Uses the left mirror once.
Feedback:
Possible to use RV only without the mirrors because everything can be seen.

Trial 4:
Rating: 9.0
See obstacles: YES
Observations:
Uses primarily the RV.
Uses the right and interior rearview mirror occasionally.
Feedback: None.

Trial 5:
Rating: 9.0
See obstacles: YES
Observations:
Uses primarily the RV.
Uses the right rearview mirror once.
Looks back once.
Feedback: None.

Overall feedback:
Pretty good.

Scenario 4: Both systems

ThroughView rating: 8.5
Rearview rating: 9.0
See obstacles: YES
Observations:
Uses RV and TV.
Uses right mirror occasionally.

Overall feedback:
TV is more intuitive. Can look straight through the car.
TV is a good supplement to RV.
Field of view is too narrow on TV. Doll is visible on RV but not on TV.
With RV, one doesnt need to keep turning the head.

B.6 Participant 6

Participant information

Name: Pan Yupeng
Age: 25
Gender: Male
Height: 1.60m
Master eye: unknown
Driving license obtained: 2007
Driving experience: 2 times (novice)
Rearview camera monitor experience: NO

Scenario 1: No aid

See obstacles: NO
Observations:
Uses primarily the right rearview mirror.
Looks back towards the end of the run to confirm distance.

Scenario 2: ThroughView(TV)

Trial 1:
Rating: 8.0
See obstacles: YES
Observations: Uses ThroughView the entire time.
Feedback:
Tiring to turn back the entire time.
Dizzy due to the shaky display.
Narrow field of view.
Objects appear very close so response is sudden.

Trial 2:
Rating: 8.5
See obstacles: N.A.
Observations: Uses ThroughView the entire time.
Feedback:
Getting used to the system.
Able to perceive distance better than RV.

Trial 3:
Rating: 8.2
See obstacles: YES
Observations: Uses ThroughView the entire time.

Feedback:
Appearance of moving objects very sudden as compared to RV.

Trial 4:
Rating: 8.4
See obstacles: YES
Observations:
Uses ThroughView the entire time.
Uses right hand to support shoulder-turning.
Feedback:
Seeing static objects is easy.

Trial 5:
Rating: 8.5
See obstacles: N.A.
Observations:
Uses ThroughView the entire time.
Feedback: None.

Overall feedback:
Very tiring to use.
Shaky display makes him dizzy.
Does not see through the rear window when using the system.

Scenario 3: Rearview camera monitor(RV)

Trial 1:
Rating: 9.0
See obstacles: N.A.
Observations: Uses the rearview camera monitor the entire time.
Feedback: None.

Trial 2:
Rating: 9.5
See obstacles: YES
Observations: Uses the rearview camera monitor the entire time.
Feedback: Rates higher because the image is clear and the frames are helpful.

Trial 3:
Rating: 9.5
See obstacles: N.A.
Observations: Uses the rearview camera monitor the entire time.

Feedback: None.

Trial 4:
Rating: 9.5
See obstacles: YES
Observations: Uses the rearview camera monitor the entire time.
Feedback: None.

Trial 5:
Rating: 9.5
See obstacles: YES
Observations: Uses the rearview camera monitor the entire time.
Feedback: None.

Overall feedback:
Difficult to perceive distance.
Sometimes cannot differentiate between object or light.

Scenario 4: Both systems

ThroughView rating: 8.5
Rearview rating: 9.2
See obstacles: YES
Observations:
Uses right rearview mirror, RV and TV.
Uses RV to observe the rear environment.
Uses TV to confirm obstacles.

Overall feedback:
Objects appear closer when using TV.
Distance perception is better with TV.

B.7 Participant 7

Participant information

Name: Tsubasa Yamamoto
Age: 24
Gender: Female
Height: 1.57m
Master eye: Right
Driving license obtained: 2006
Driving experience: hardly. 4 years have past since the last drive.
Rearview camera monitor experience: NO

Scenario 1: No aid

See obstacles:
NO for static(doll)
NO for moving(ball)
Observations:
looking back.
Feedback: none

Scenario 2: ThroughView(TV)

Trial 1:
Rating: 9.0
See obstacles: YES
Observations:
successfully used TV
only used TV
Feedback:
compared to the side mirror, it is easier to know if the car is straight.

Trial 2:
Rating: 8.0
See obstacles: N.A.
Observations:
used side side mirror and the TV alternately
Feedback:
(Why downgrade?) without any obstacles, its hard to judge the system.

Trial 3:
Rating: 8.0
See obstacles: YES

Observations:
Looked at the front information board quickly while using TV
Feedback:
nothings changed. Just same as the 1st trial.

Trial 4:
Rating: 8.0
See obstacles: YES
Observations:
used TV only
Feedback: could see the obstacle but couldnt identify what it is.

Trial 5:
Rating: 7.0
See obstacles: NO
Observations:
used TV only
Feedback: same as the 2nd trial. getting comfortable

Overall feedback:
It is good that the system can be used by just looking back.
It is even better it i could see other information such as speed.

Scenario 3: Rearview camera monitor(RV)

Trial 1:
Rating: 8.0
See obstacles: N.A.
Observations:
only used the RV.
seemed very uncomfortable to use RV
Feedback: None.

Trial 2:
Rating: 9.0
See obstacles: YES
Observations:
gazed at the RV
Feedback: RVs guideline helped to know the car direction.

Trial 3:
Rating: 9.0

See obstacles: N.A.
Observations:
gazed at the RV
Feedback: wider view is good.

Trial 4:
Rating: 9.0
See obstacles: YES
Observations:
gazed at the RV
Feedback: resolution is higher than TV, and could see the what doll was that.

Trial 5:
Rating: 7.0
See obstacles: YES
Observations:
gazed at the RV
sometimes
Feedback: could see the rolling ball using side the side mirror

Overall feedback:
wider view helps a lot, except the distance perception.

Scenario 4: Both systems

ThroughView rating: 8.0
Rearview rating: 8.0
See obstacles: YES
Observations:
used TV mostly, and used RV

Overall feedback:
TV is good in terms of perspective. and is good for close up.
RV is good for wider view and resolution.
Looking back is not a problem. better than open the door and looking back.
cannot keep looking back. Need to know other info such as speed.

B.8 Participant 8

Participant information

Name: Wayne Mc Lemore
Age: 29
Gender: Male
Height: 1.81m
Master eye: Right
Driving license obtained: 2000
Driving experience: 2 times daily for 11 year (expert)
Rearview camera monitor experience: NO

Scenario 1: No aid

See obstacles: NO
Observations:
Uses right and interior rearview mirrors.
Looks back.
Feedback:
Just as how he would always have done it.

Scenario 2: ThroughView(TV)

Trial 1:
Rating: 5.0
See obstacles: YES
Observations:
Uses primarily TV.
Uses interior mirror.
Feedback:
Either look back through the window or down at the seat screen. A bit distracting.

Trial 2:
Rating: 6.0
See obstacles: N.A.
Observations:
uses TV.
raises head above half-mirror to see behind.
Feedback:
Getting used to it.
Finds it a little difficult to look back. Stiff back.

Trial 3:
Rating: 6.0
See obstacles: YES
Observations:
Uses TV.
wants to put arm behind seat to adopt a more comfortable position.
Feedback:
Getting easier to use.

Trial 4:
Rating: 7.0
See obstacles: YES
Observations:
Uses TV.
Looks above half-mirror to see behind.
Feedback:
Getting easier to use.
Distracted by shadows on the seat.

Trial 5:
Rating: 7.0
See obstacles: NO
Observations:
Uses TV.
Looks above half-mirror to see behind.
Feedback: None.

Overall feedback:
Good for tight parking, for getting close the wall.
Good for spotting low objects.

Scenario 3: Rearview camera monitor(RV)

Trial 1:
Rating: 5.0
See obstacles: N.A.
Observations:
Uses primarily RV.
Uses right mirror.
Feedback:
convenient. doesnt have to turn back.

but have to switch between right mirror and screen, as well as looking back to judge.
compared to up-down glancing with TV.

Trial 2:
Rating: 6.0
See obstacles: YES
Observations:
Uses primarily the RV.
Uses right mirror.
Looks back.
Feedback:
wider view. can see more.
want to see actual view to judge close-up.

Trial 3:
Rating: 6.0
See obstacles: N.A.
Observations:
Uses primarily the RV.
Uses right mirror.
Looks back.
Feedback:
want to know how close the wall is but doesnt know.
want to see actual view. find it hard to trust the screen.
doesnt feel right.

Trial 4:
Rating: 6.0
See obstacles: YES
Observations:
Uses primarily the RV.
Uses right mirror.
Looks back.
Feedback: getting comfortable but still doesnt feel it is enough.

Trial 5:
Rating: 7.0
See obstacles: YES
Observations:
- Uses primarily the RV.
Feedback: getting used to it.

Overall feedback:
Dont have to look back. If back hurts, it will be super useful.
Lines are helpful but also distracting.

Scenario 4: Both systems

ThroughView rating: 6.0
Rearview rating: 6.0
See obstacles: YES
Observations:
Uses RV and TV.
Uses TV to confirm obstacles.

Overall feedback:
with TV, it is easier to look back out and easier to switch.
With RV, can see everything including bumpers, easier to judge position of objects but not the distance to.
With TV, cant tell how close because cant see the bumper.
With RV, shifting attention is distracting.
If TV has a wider field of view, it will be better.