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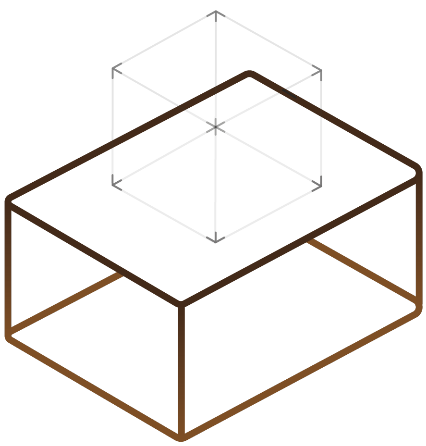
Faculty 03: Mathematics and Computer Science

DelivAR: An Augmented Reality Mobile Application to Expedite the Package Identification Process for Last-mile Deliveries



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Abstract

The rise of mobile Augmented Reality (AR) applications presents itself with many opportunities to the vast and complex logistics market. This industry has considerably changed in the past years, especially in Europe. The transformation led to a simplified delivering process, obtained by eliminating intermediate steps, as well as adopting new technologies for courier operations. In the same way, AR solutions have been implemented and tested in logistics by using head-mounted displays. Nonetheless, the smartphone segment was not highly utilized for AR due to performance limitations. Hence, our approach presented in this thesis is relevant to last-mile delivery companies, a growing business phenomenon during the past years, which have already adopted mobile devices for most of their internal operations.

We present the design, implementation and evaluation of DelivAR. DelivAR is a mobile web AR application that creates a novel approach for the package identification process. This solution can assist the couriers during the drop-off. At this moment, the drivers must rely on their memory when delivering the packages to the customer. The web app was built with an open-source library called AR.js and using the programming language JavaScript. Technically, this AR application recognizes fiducial markers, printed images placed in a real scene that are traced by the smartphone camera. We evaluated the procedure within a technical study, analyzing the identification time of a fiducial marker performed by different smartphones in various states. Furthermore, we posed a qualitative analysis of the mobile application to measure its use. Our approach for this study was a semi-structured interview with an expert in logistics. We developed this project with the support of a last-mile delivery startup based in Stockholm, Sweden.

Keywords: Augmented Reality, WebAR, Marker-based Recognition, Logistics Operations, Last-Mile Delivery.

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Chapter 1

Introduction & Motivation

Studies show that, during the last twenty years, the final stage of the urban supply chain for the Courier, Express and Parcel (CEP) companies has been continuously improved [22]. Additionally, the revenue estimation for the future of the CEP market shows a constant growth, especially in Asia (see fig.1.1). In the same way, the spread of new technologies and the advent of economic and social changes prompted the emerge of new shopping methods and logistics patterns have emerged which lead to a growth in transportation [14]. Thus, part of the CEP sector is restructuring itself to tackle the specificities and constraints of urban distribution in a rapidly changing context, creating what we could call an urban parcel delivery segment, with specific organizations, tools and strategies [10]. Confronted with the growing complexity of the 'last-mile' segment, the traditional actors of the CEP sector in Europe are evolving together, with their strategies, tools, and organizations [35]. This analogy is also mentioned by Ducret [10], who describes the last-mile delivery business as highly innovative and environmentally friendly, specialized in urban parcel delivery within the business to customers (B2C) segment. Its creation follows the rise of e-commerce and its nature is innovative, characterized by a start-up structure, which can be flexible and fast-acting [22]. The last-mile delivery companies tackle market niches, providing innovative and high-value delivery solutions based on new technological tools. Although this new business sector has led to more expensive services within the final

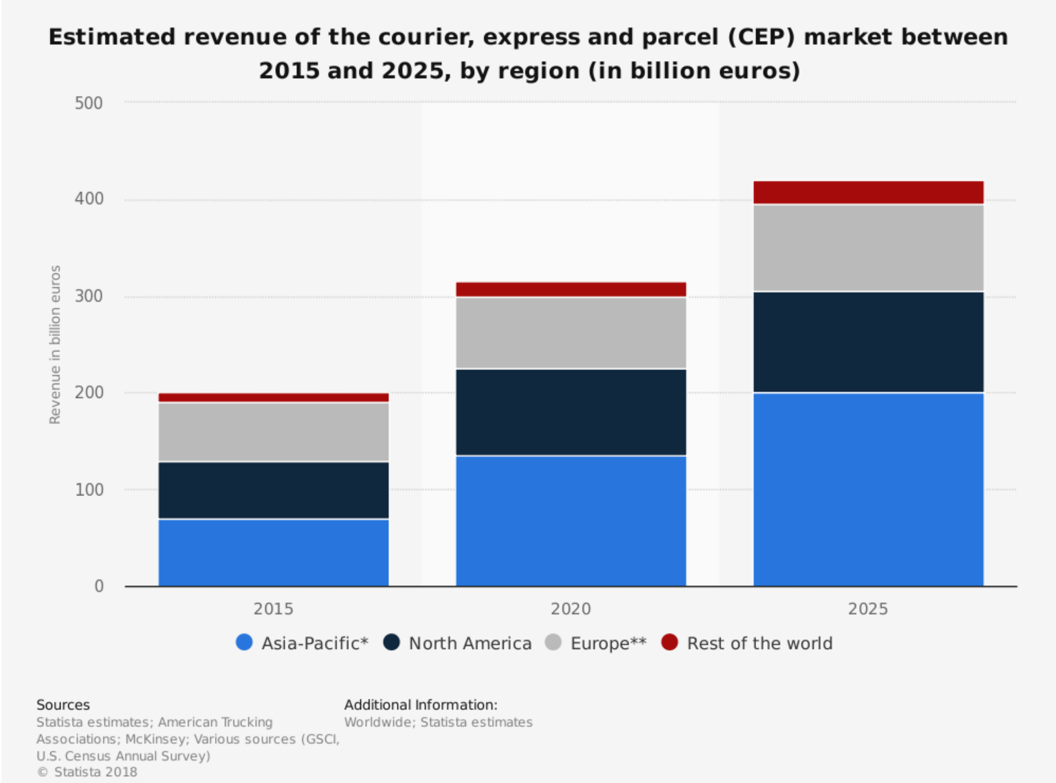


Figure 1.1: Estimated revenue of the CEP market within the next 10 years [60].

step of the supply chain, it is a promising field for the development of interactive applications [13]. The interaction with humans can be achieved via the use of mobile devices that can act as the interface for bidirectional communication. The advances in mobile communication systems provide various opportunities for companies in the logistics business [30]. One such example is assisting the couriers during error-prone operation procedures with devices [39]. In addition, the augmented reality (AR) technology can be combined with agents to support operators in other different tasks [20]. In the following chapter, example of AR applications are presented.

One of the tasks within the last-mile operations where the AR technology can serve is the drop-off activity. The moment described is one of the last steps of the parcel delivery procedure, when the courier has arrived at the final delivery address. This particular maneuver is a time-consuming task. Currently, to find a package inside the car, drivers must rely on their memory of the loading process. Findings show that 40% to 60% of the time spent by the courier is to locate the right package within their truck [13]. Using AR can facilitate this operation by employing an application that will run on the smartphone used by the couriers. This thesis discusses a possible implementation of an AR web-based solution to the aforementioned problem.

In comparison, similar AR programs were developed in the past which focused on the warehouse operations by using a head-mounted display [31]. The possible operations where AR can perform and possibly improve the process include receiving, storing, picking and shipping parcels. This technology has certain limitations and issues that are tied to high costs and difficulties in use and learning [34]. On the other hand, with the advent of the smartphone, businesses increasingly rely on this device as their primary productivity tool [17]. Mobile applications as an extension of the functionality of smartphones, built the basis for the implementation of location and time-independent business models [30]. Specifically, in logistics, the combination of a crowdsourcing system combined with mobile devices created a new scenario, making it possible to assign tasks remotely to each worker and optimizing the service [39].

WebAR is a potential approach and solution towards AR software implementation on a smartphone [21]. We actualised the concept by using the library AR.js, which is written with JavaScript programming language. We developed an app by using this technology, and we called it "DelivAR". The application is based on open-source libraries most importantly ARToolkit, an open-source AR library created originally by Hirokazu Kato [54]. Previously, researchers tested this software on computers by using a fiducial marker measuring system [19], [18]. The study aimed to determine the efficiency of this library through an extensive analysis of the fiducial marker design. As the performance of ARToolkit on smartphones might differ from computers, we developed DelivAR to further test its capabilities. DelivAR is a cross-platform app with a graphical UI and AR features. It displays a three-dimensional cross-hair shaped like a swoosh on top of the fiducial marker and an identification time code at once. The identification time measures its value from the moment the app starts until it recognizes the marker. This data is collected to conduct the technical study based on:

- different lighting conditions,
- camera to marker distance,
- smartphone make and model,

The information later helped to analyze the performance level of the application. Moreover, we made a qualitative study, pursuing an evaluation from a logistics expert. In this situation, we interviewed a courier of Airmee, a logistics company based in Stockholm, Sweden. By using a semi-structured interview, we delved first in the current technology used by the company's fleet. Among the questions included in the study, we asked about the involvement of CPT system in their daily task and normal work conditions. Finally, we made an active user testing of DelivAR, afterwards questions and observations of the usability of this application were discussed.

Chapter 2

Related Work

In this part of the paper, the Augmented Reality (AR) concept is described and the previously discussed case study is presented at length. The last part of the chapter will focus on the qualitative studies carried out in this thesis, specifically an interview with an expert — a courier of a logistics company.

2.1 Augmented Reality

Visual figures can help in providing clear and exhaustive directions to aid elaborate textual information [29]. Usually, images would accompany the text to provide more precise information and make the content more understandable. In some cases, the annotations and animations are more accessible to grasp when seamlessly integrated into real-world images. Therefore the cognitive load necessary to interpret the initial information can be reduced [25].

AR is computer generated information superimposed over the real environment with the use of dedicated AR devices in real-time [3], aiming for the enrichment of visual information, changing how the use perceive the virtual content [29] and facilitating the understanding of a written concept as aforementioned.

It is important to learn how to distinguish AR from Virtual Reality (VR) [3] and Mixed Reality (MR) [24]. According to Azuma [3], an AR system has three fundamental characteristics:

1. It combines real and virtual elements;
2. It delivers real time interactions;
3. Superimposed objects can be placed within three-dimensional space;

This definition might be better understood by thinking about movies, for example the movie "Avatar". It features photo-realistic virtual figures seamlessly blended in a real environment (cf. 1 and 3), yet they are not interactive in real-time (cf. 2), but rendered in post-production.

Milgram and Kishino described Mixed Reality as an existing medium within the range of Real Environments and Virtual Environments. The spectrum is known as the Virtuality Continuum. The term Augmented Reality refers to an action in which a real environment is "augmented" with virtual (computer graphics) objects [24].

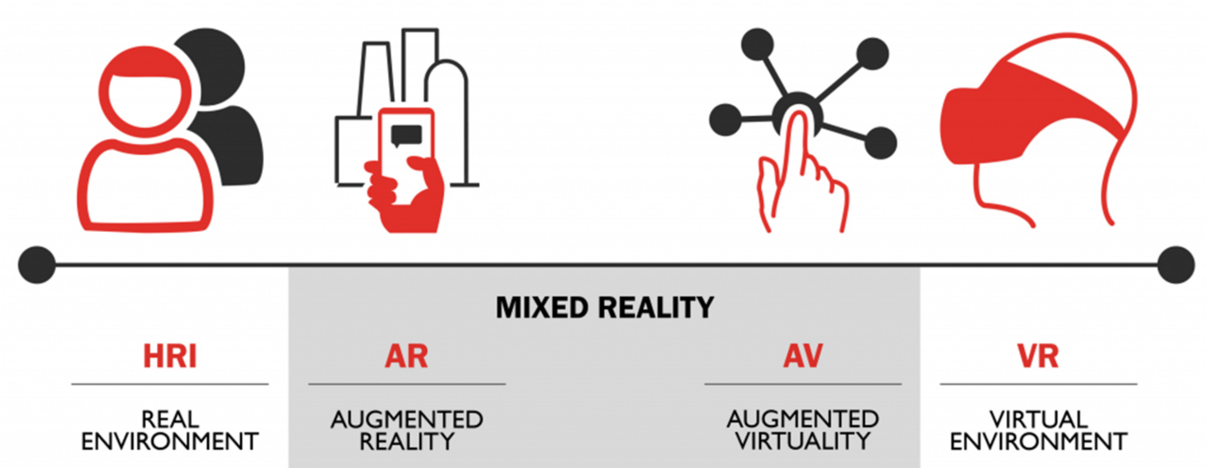


Figure 2.1: An adapted representation of the Virtuality Continuum [57].

A Virtual Environment (fig. 2.1) also known as Virtual Reality is a system that provides a "complete immersion of a user inside a computer-generated environment". The Virtual Reality head-mounted displays (HMD) are defacto the entry point device for those experiences [3]. The combination makes the consumer perceive these machines created visuals as a different surrounding, possibly a distinct reality. On the other hand, AR provides "virtual objects superimposed upon or composited with the real world" [3]. The 3D enhancement of complementary information made in real time and imposed on reality might be applied in different scenarios, such as teaching and learning [6]. It can also involve other senses of the user [36], although in this paper, the focus will be only on the visual aspect. Generally, Augmented Reality has become increasingly relevant as a research field, and several applications can be found on the Internet, produced in industry, art or recreational contexts [3]. The technology is expecting to reach a market size of almost 200 billion U.S. dollars by 2025 (see fig. 2.2). In the lower section of this chapter paragraph, presented will be examples of applications that describe the vast possibilities of AR.

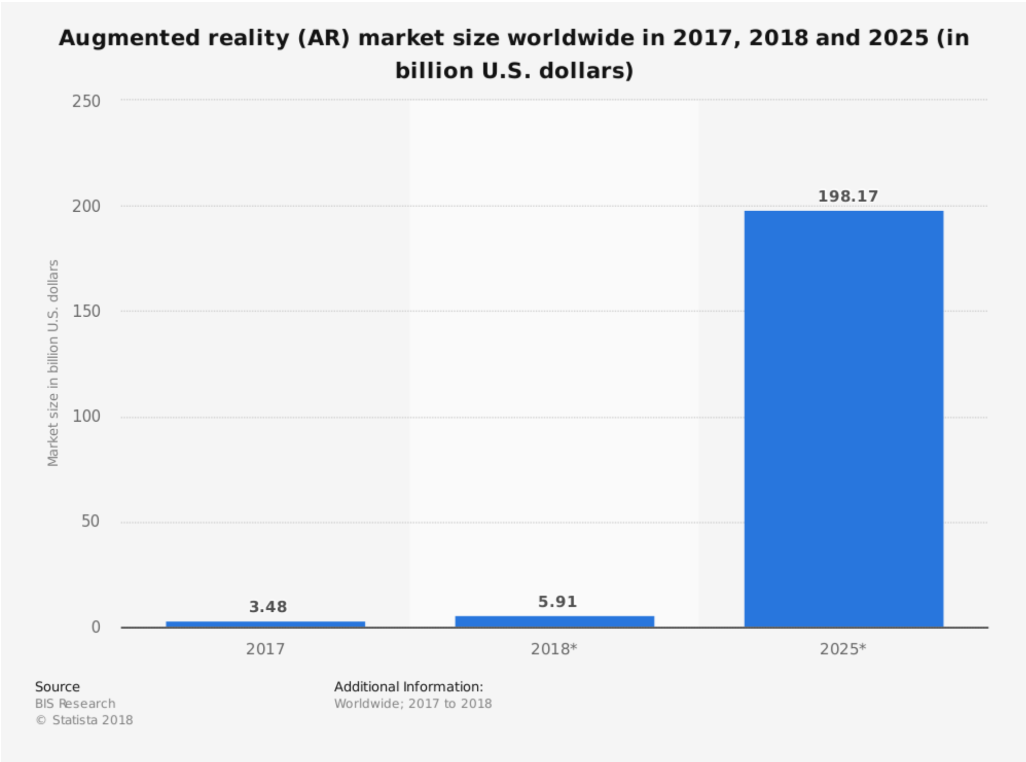


Figure 2.2: Augmented reality market size in the next years [47].

2.1.1 AR Systems

Despite the platform where AR operates, many improvements occurred during the past few years. Within the industry sector, it appears that the use of a dedicated device, such as Head-Mounted Display might be more beneficial than the smartphone [34]. In warehouse operations, for example, the benefits of Augmented Reality HMD include hands-free activities, limited decision making required and portability of information [34]. By the time of this project, two examples of industry AR platforms are Microsoft Hololens (see fig. 2.2 (b)) and Vuzix M300 (see fig. 2.2 (a)).

(a) Vuzix M300 [67].

(b) Microsoft Hololens [56].

Figure 2.3: Two models of HMD used in warehouse operations.

Contrarily, in the smartphone sector, advancement in software and hardware happen nearly every day. Apple is investing significant resources in ARKit [43], initially integrated into iOS 11 and released in September 2017. By the end of 2018, ARKit 2 is expected to be available on iOS 12, with features like multiple users simultaneously experiencing the AR application, improved integration of real-world objects within the AR experience and much more. Google stopped the development of their early AR platforms — Glass and Tango; in favour of its ARCore framework [50] that can reach a considerably larger number of the public through its Android OS integration.

(a) Markless Tracking [50].

(b) Multiplayer AR game [43].

Figure 2.4: Examples of applications made with Google ARCore and Apple ARKit.

A new feature recently included in these frameworks is the possibility of realizing AR application with markerless approach. It also introduced the concept of Anchors [51] (AR Anchors in Apple ARKit [46]), which describes an approximation of a fixed location and orientation in the real world. The Anchors are registered and stored in the Anchor Cloud. The Cloud data can be used in a multi-user experience to establish a common spatial reference across users and their devices.

An alternative AR framework to Google and Apple systems is the software Unity backed with the Software Development Kit (SDK) called Vuforia [64]. The combination of both programs allows the user to create seamless AR application by using Computer Vision technology to recognize and track planar images (Image Targets) and display above them 3D objects in real-time. Initially tested as possible approach for this thesis, Vuforia allows developers to build customized application through their web library[65], where is possible to upload customized image targets employed inside the Unity Software. Unlike traditional markers used in first AR tools years ago, these pictures do not need particular black and white regions or specific shapes to be recognized. The SDK detects and tracks the features against a known target resource database. When the Image Targets are identified, the SDK traces the picture as long as it is visible in the camera's field of view. However, these markers must be upload in the Vuforia Target Manager [66], which requires the registration on the platform and it presents some limitations within the free account. Once the markers collection is uploaded on the Vuforia website, the development is done in Unity. Initially, the software requires few elements:

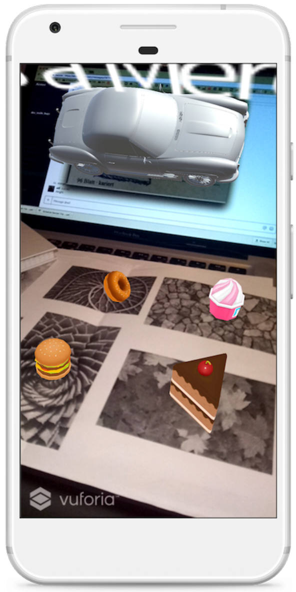


Figure 2.5: Example of Android app created by the student with Vuforia

- **ARCamera**: the element contains the image targets uploaded to the Vuforia Target Manager. Those pictures are imported and activated in Unity.
- **ImageTarget**: once placed it within the project, it is possible to link the image target

database and value.

- **3DObject**: the object will define a unique connection to the marker, the 3D element can be resized and moved to be perfectly aligned to the printed target.

It is possible to create an AR application by only using these three elements. The outcome can be a mobile application for either iOS or Android devices.

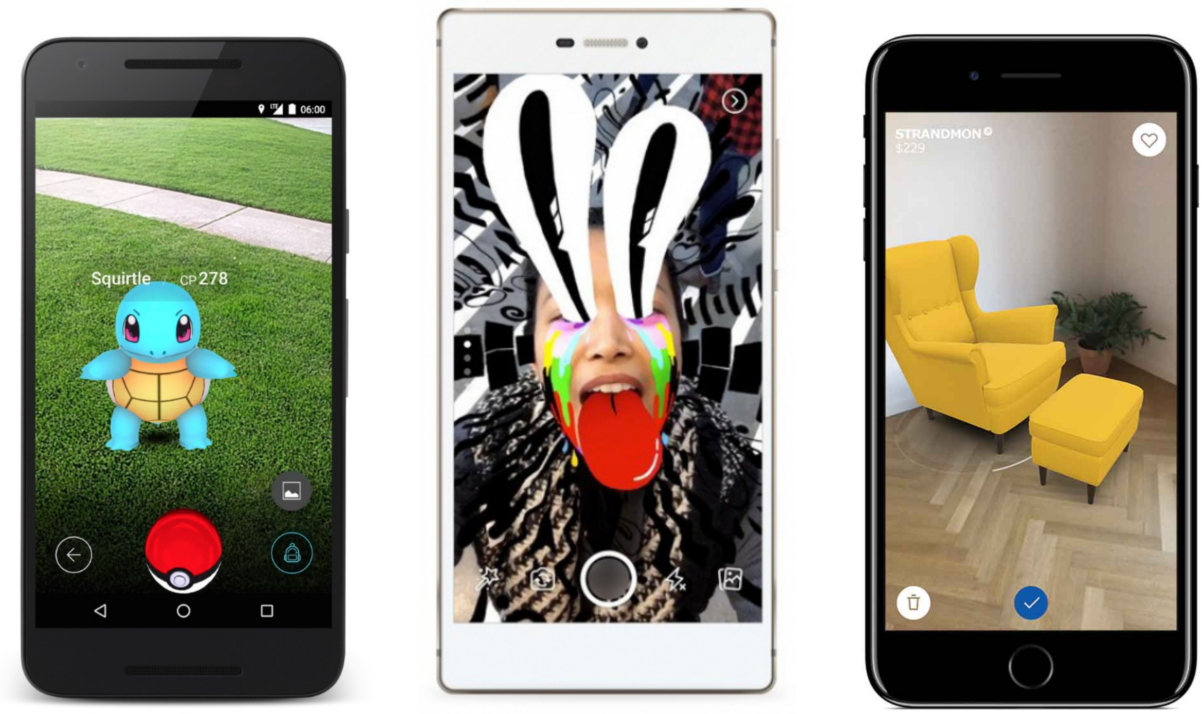
During the past years, AR increased in popularity due to the availability of commercial SDK with which mobile devices such as smartphones and tablets have full support of the AR technology. These capabilities are performed within native apps built with proprietary SDKs, such as the aforementioned ARKit, ARCore and Vuforia. On the other hand, an example of WebAR allows AR experiences to run entirely in the browser of the smartphone, with the combination of HTML, CSS and JavaScript [21]. This library is called AR.js, and it is used as the main tool of the thesis. It is mainly a combination of three open-source libraries: A-Frame, Three.js and ARToolKit. The latter is the one used to interact with the physical world, easy to configure, well-documented and widely used in AR applications. It is the only AR library which has an open-source marker detection algorithm [18]. In the following chapters, the technical aspects of AR.js will be described and how this tool can be an initial AR solution for logistics businesses.

2.1.2 AR Applications

Three different examples of popular AR programs are presented to reveal the enormous possibilities of this technology: Pokémon Go [59], Camera Effects by Facebook [49] and IKEA Place app [53].

- The AR mobile game Pokémon Go (see fig.2.4 (a)) interacts with the real environment through the use of the smartphones global positioning system (GPS). The mission of the game is to locate and eventually capture virtual creatures called Pokémon, which appear on a smartphone screen as if they exist in the player's real-world location. Findings showed that Pokémon Go has been able to increase physical activity across men and women of all ages, weight status, giving this form of game heads to increases in physical activity with significant implications for public health [1].

- Camera effects developed by Facebook (see fig.2.4 (b)) are integrated camera features within the most popular social media platforms, such as Instagram and Messenger by Facebook. This is an example of the several applications that enhance features of a smartphone camera. The application creates interactive experiences that increase the user presence in the social network. Depending on the use, people can then take a photo or record a video that blends the camera effects with the captured images.
- The IKEA Place, available from late 2017, allows people to virtually place furniture in their home. The app (see fig.2.4 (c)) gives the possibility to scale and place over 2,000 pieces of 3d furnishing superimposed with the real environment. Opening the application for the first time initiates computer vision algorithms that scan the nearby area via the smartphone camera. Captured spatial features are then used to give an estimation of the users environment and trigger AR content in this case, the IKEA furniture.



(a) Pokémon Go

(b) Camera Effects by Facebook

(c) IKEA Place app

Figure 2.6: Examples of popular AR applications

2.1.3 AR in Logistics

Recently, AR has been a topic of interest to researchers and practitioners due to its potential to support manufacturing and logistics processes. This technology is considered as a new emerging area for mobile cyber-physical applications [40]. Additionally, AR appears to be an advantage that could bring "the next wave of change" in the industry [13]. Moreover, it has been recognized as a crucial technology to be considered supportive of the operation of the CPS in existing environments [20]. In the logistics, the AR technology has been introduced with AR dedicated head-mounted displays (HMD) for seamless connection between the human and the technical system [31]. The primary task of the device is to display the necessary information to the professionals operating in a warehouse. The AR system could ensure quality control by monitoring each work step (via enhanced image recognition) and detecting errors in the assembly process [13]. The device interaction and experience should be robust, and it should not limit the worker's freedom of movement [31]. Generally, in warehouses, the applications made with AR could perform in four key operations: receiving, storing, picking and shipping [34]. In this paper only picking and shipping operations will be considered (see tab. 2.2).

Table 2.1: Potential uses for picking and shipping operations in Warehouses.

Operation	Potential uses
Picking	Display picture and details of the item to be picked
	Highlight the physical location with the item required
	Inform about errors and disruptions
	Scan the items barcode to assign to picking cart or to see more information
Shipping	Show the best way to place picked items in a package
	Show where to place each order in a truck
	Indicate appropriate loading area
	Check/Count products/orders that are being delivered

It is important to highlight the similarities with the procedures of last-mile deliveries. Also, the devices used by this business is mainly smartphones [39]. Admittedly, smartphone allowed

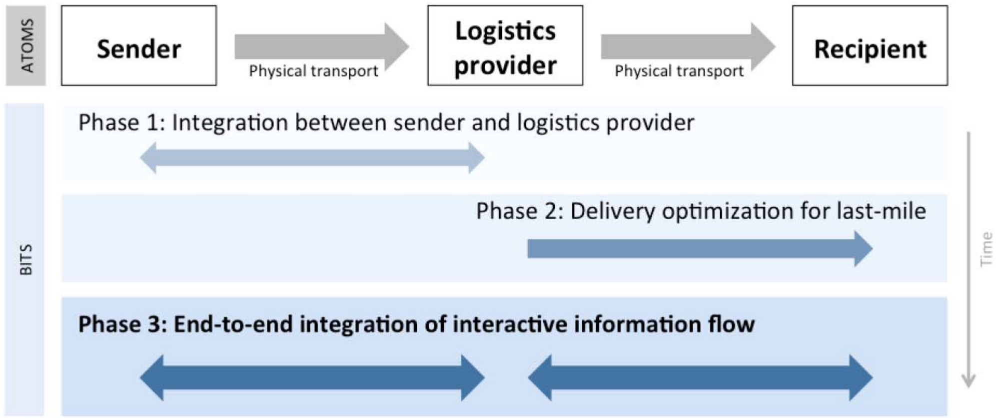


Figure 2.7: Utilization of information in logistics [30].

recipients to open a communication channel to logistics providers as well as to senders and therefore support further transportation optimization [30].

The right side of fig. 2.7 shows the optimization of the physical transportation by the use of information systems like route navigation [39]; this area can be tackled by personal computers that allow recipients to inquire information about their shipment [30]. Moreover, the camera of a mobile device provides a faster and more reliable solution for scanning bar-codes and QR compared with the HMD integrated camera. The battery and the general usability of the headset, even if they improved with the recent HMD devices, are still not specifically designed for an extended period of use, which can cause discomfort symptoms. Cost and maintenance of HMD devices is relatively higher; whereas alternative smartphone IT solutions are significantly cheaper [34].

Therefore,an AR application made on the smartphone can be helpful for the last-mile delivery business. Among the tasks that can be improved with AR, it is important to mention: parcel loading and drop-off, last-meter navigation and AR-secured Delivery using facial-recognition technology [13]. This thesis focuses on the drop-off activity which is one of the last step of a parcel delivery procedure; the moment after the courier has arrived in the destination. Drivers spend between 40% and 60% of their time locating the correct parcels in their vehicle [13].

The use of the smartphone as a primary working tool by the last-mile delivery firms opens up the question on which AR system might suit better to solve the described problem. The student compares the systems described at the beginning of this chapter, highlighting factors such as marker-based solution, old device compatibility, open-source code availability.

Table 2.2: Similar AR frameworks

	ARKit	ARCore	Vuforia	AR.js
Marker-based application	✘	✘	✔	✔
Open-source System	✘	✔	✘	✔
Cross-platform app	✘	✘	✔	✔
Run on old Smartphones	✘	✘	✔	✔

The comparison of the presented AR systems as well as the high motivation of the student leads to AR.js framwork as a solid choice for mobile application development. The reasons behind are the possibility of building a web-based cross-platform AR program that can operate on mobile devices. Furthermore, the AR.js library is open-source and free to use, with no registration or subscription required. This choice also presents few limitations: the development restrictions of a marker-based AR solution and the lack of features which the open-source library can imply.

2.1.4 Fiducial Markers

The choice of AR.js as the primary development tool of this thesis introduced some considerations regarding its marker tracking feature. Almost all open-source AR libraries use the look-similar markers, characterized by a solid black square as border [38]. An advantage of the square markers is the natural process to extract the information (like absolute 3D position and orientation) required for AR uses. In order to distinguish different targets, each marker contains unique features inside the black square. The detection of these inner parts of the markers is the part where the ARToolkit shows recognition acceptable results [38].

This extracted information can be used in different ways, the most explicit being to use the marker ID to trigger some behavior dependent only on the presence of a marker such as controlling the access inside a building [11]. In this thesis, the marker is tested on its reaction time, and it will show a 3D object as visual confirmation of correct marker detection for the user.

Hence, the technical study will analyze the tracking performance of AR.js, and the software will run on different smartphones. The process will follow some of the experiments that have been made on ARToolKit and operated only on computers [18], [19]. The findings identified eleven factors (see fig. 2.5) that affect the marker quality grouped into four sub-categories: marker shape, marker placement, software, and hardware:

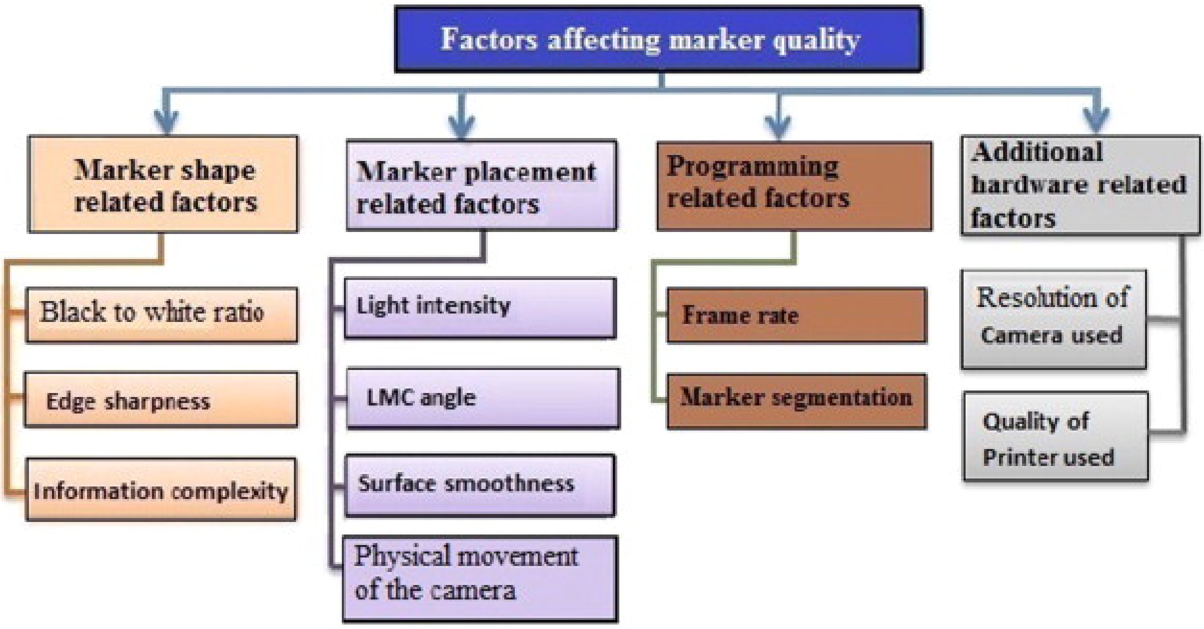


Figure 2.8: The eleven factors that affect the marker quality [18].

The marker placement and the hardware are the categories that have been considered by the student in this work. The following factors interest on how to place the marker in the real world environment so that the video camera can easily and accurately detect it [18]:

- *Light Intensity*: The luminance of light is very necessary. The computer camera cannot detect the passive markers in the absence of light and even very bright light; The following measures (see fig. 2.6) on light intensity are considered in the unit of Foot Candle (FC);
- *Light-marker-camera (LMC) angle*, it is the angle made between light source, marker and camera. The light source means the origin from where the light is coming. It may be a light generating torch or a bulb or even a window in a room. If normal to the marker surface is anti-parallel to the camera and the LMC angle is within a certain range.

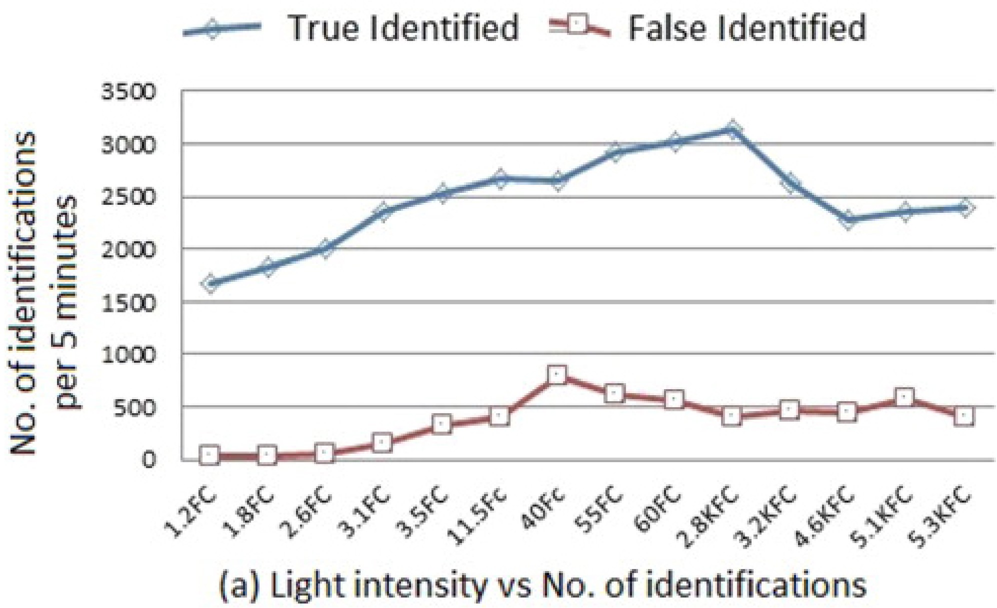


Figure 2.9: The results of the experiment with different light intensities [18].

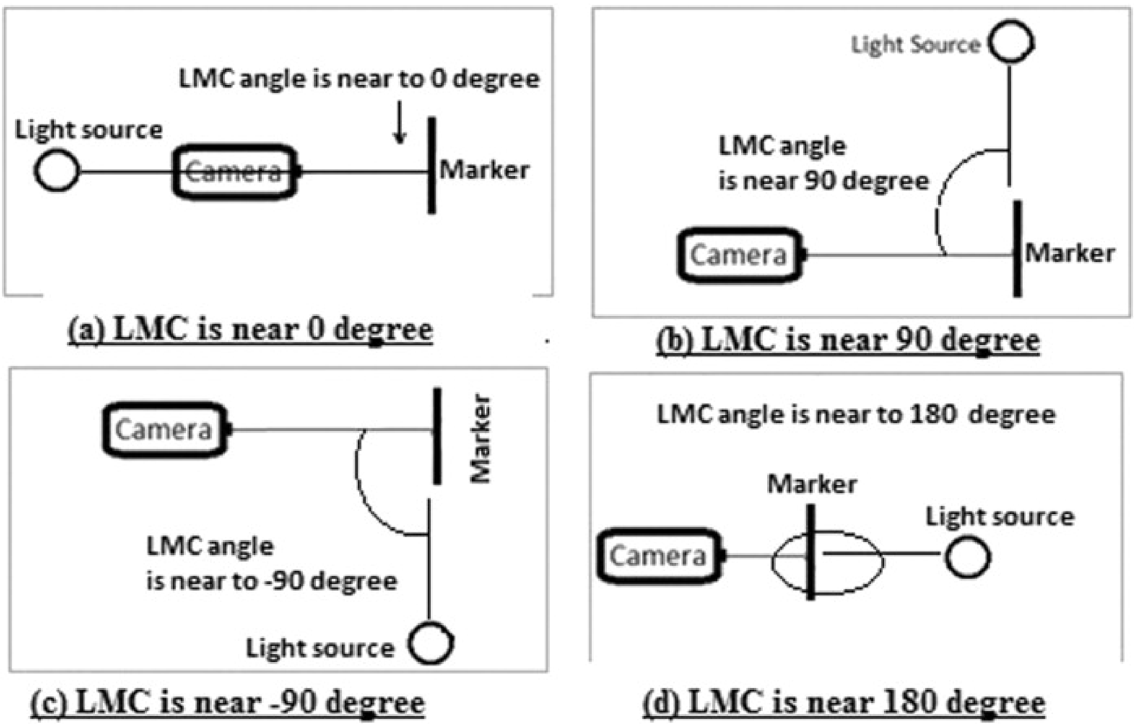


Figure 2.10: Various LMC angles [18].

- *Resolution of the camera used.* Higher resolution cameras help in more accurate and quicker detection [18]. Webcams with different resolutions were the only cameras used in this experiment. In the table 2.1 the features of the three cameras used. The final results of the test are shown in fig. 2.9, which show that camera 1 is the best in this case.

Table 2.3: Various cameras used for the experiments [18].

Named used for the camera	**Camera's description**	**Camera Resolution**
Camera 1	A4tech (PK-835G)	16 Megapixels
Camera 2	Logitech (Orbit AF)	3.7 Megapixels
Camera 3	HP Webcam 101	1,3 Megapixels

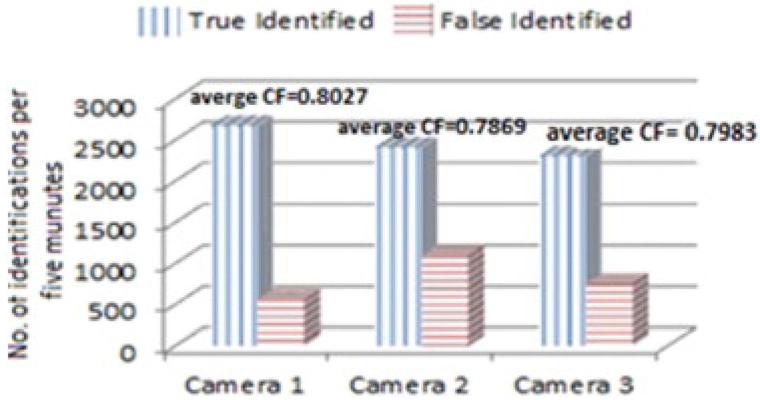


Figure 2.11: Identification Time with different Camera Resolutions [18].

2.2 Qualitative Studies in Logistics

The opportunity of working together with a last-mile logistics company gave the student the chance to explore more the logistics sector. Sharing experiences and knowledges with colleagues, not only from the technical group, opened new possibilities for the thesis development. In this scenario, a qualitative study might be the possible approach to further analysis.

In this scenario a qualitative study has been thought as a possible solution, in relative terms, talking to experts in the exploratory phase of a project is a more efficient and established method of gathering data than, for instance, participatory observation with surveys [5]. Therefore it is possible to say that an individual is considered an expert if she or he possesses an "institutionalized authority to construct reality" [15]. Gorden [12] defines an expert as an individual who is not restricted to activities in local contexts, all of these actors acquire a specific knowledge through their daily tasks because they have advantaged access to information. These learned instructions and knowledge acquired through carrying out such functions is the subject matter of the expert interview. The aim is directed therefore towards the modes and mechanism of producing knowledge, that is to an understanding of the mechanism by which this expertise is generated, checked, communicated, and finalized [4]. Finally by conducting an expert interview can serve to shorten time-consuming data gathering processes, mainly if the expert is seen as a credible source of practical knowledge and are interviewed as surrogates for a wider circle of players [5].

An "interview" include the ability to structure questions, listen attentively [8], pause, probe or prompt appropriately [9]; and encourage the interviewee to talk freely, making it easy for the interviewees to respond [8]. According to Mentzer [23], the logistics discipline is dominated by quantitative and positivist research, perhaps arising from the nature of logistics as an applied science with strong engineering roots. Although it is crucial to highlight the necessity to combine the qualitative analysis with the quantitative methods when it comes to research in logistics, Naslund [28] for example has pointed out the necessity to use both methods if we need to develop and advance logistics research. This horizon has since broadened, with qualitative research perhaps entering a more solid stage as evidenced by Sachan and Datta's [33] analysis of almost 450 articles from three leading logistics journals published between 1999 and 2003. They demonstrated that while the majority of publications still use quantitative methods, there is a shift towards more qualitative techniques. They concluded that the growing maturity of the discipline might cause such increased acceptance and the focus on more why and how questions.

By looking an another case, Hussey and Hussey [16] noted that it is usual to conduct action research within a single organization and that it is thus similar to the case-study approach in many of its procedures. The case study they presented is an extensive examination of a single instance of a phenomenon of interest. Moreover, Voss [37] observed that case research has consistently been one of the most powerful research methods in operations management, in particular in the development of new concept, in which this project may be the case. As aforementioned, the expert evaluation comes as supportive analysis of a technical study. In this setup, the author can use information previously acquired to construct an interview that is more focused and relevant to the research questions [26]. By analyzing the overall possibilities and the availability of the professionals, the student decided on a semi-structured interview (SSI). SSIs are designed to collect subjective responses from interviewees regarding a particular situation or phenomenon they have experienced [9].

Moreover, SSI has been chosen for this research also for practical reasons: the logistic company named Airmee has employed the student for six months. Therefore he had the opportunity to meet logistics professionals, such as managers and couriers. Albeit the knowledge of the student on the subject of logistics is moderate. Nevertheless, Drever states [9], if an expert is approached correctly, then the interviewer can expect the person to treat the discussion seriously and answer all the questions. This resolution includes explaining any ambiguities and misunderstanding. As a result, the questioner can expect to get a complete set of valuable data, such as the expressiveness, the manner, and the body language.

By comparison with interviews, questionnaires are inflexible once they are in print. A researcher has limited control over them once they are in the mailimprobability to get the answer back, incompleteness of the answers, misunderstanding, etc. [9]. Generally, an interview gives more data to be analyzed and summarizing some passages might be challenging to do it in real-time, for this reason, a voice recorder is used to document the process.

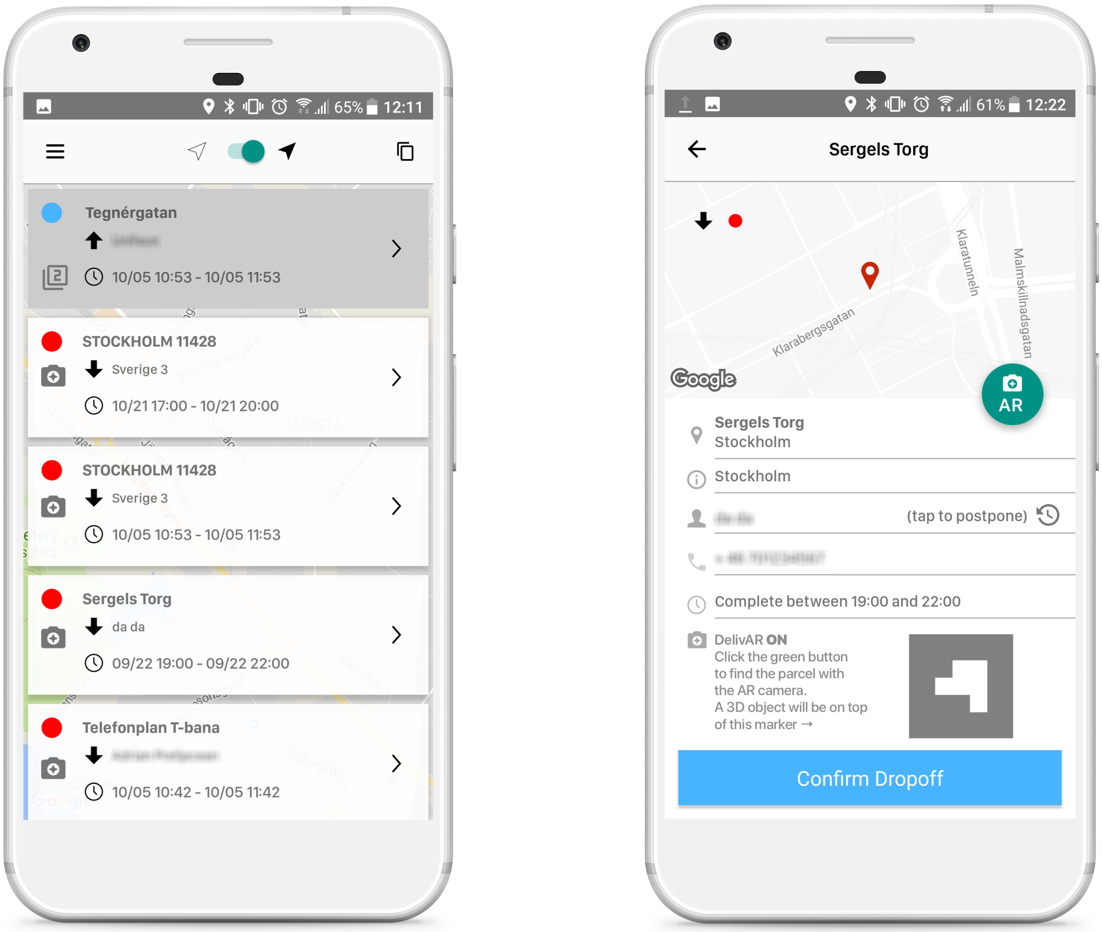
Chapter 3

Concept

In this chapter, the student describes the concept creation process of the AR application. The idea of this study came in symbiosis with Airmee [42], a last-mile logistics startup based in Stockholm, Sweden. The company, founded in 2016, has built a platform that employs machine-learning technologies and AI algorithms developed in-house to optimize last-mile deliveries. Initially, the idea for this project was to find a tool that might be integrated inside the mobile application used by the couriers. As mentioned in the related work, one use of AR can be in the moment of the drop-off. In the critical stage when the courier is finding the parcel inside the car, right before delivering to the customer.

3.1 DelivAR's Design System

DelivAR began as an idea of integration in Airmee's courier app. Currently, the company is using a native application for Android. In the workplace, it has been utilized daily by the company's couriers for a couple of years, and it is continuously improving. DelivAR design system combines the company app with AR functionalities. The app would present three views: list of orders, order overview, DelivAR camera. Hence, the first stage of development of DelivAR was focused on a design thinking process to integrate the program inside Airmee's courier app. The perceptual patterns chosen follow the guidelines of Google's material design library [52].



(a) List of dropoffs and pickups in the app. (b) Overview of the order.

Figure 3.1: Two views of the Airmee app.

The logistics operations start after tapping on the slide toggle placed on the headline (see fig. 3.1 (a)) that also activates the Global Positioning System (GPS) of the smartphone. In this view, the list of deliveries presents two colors: blue for pick-up from retailers and red for drop-off to recipients. Furthermore, information about the name of the retailer (or the city area) together with possible date and time of the delivery are displayed on the card. The camera icon shown in the left side of some elements informs the courier that the DelivAR camera is available for that order.

By clicking on any card, the order overview page will appear (see fig. 3.1 (b)). Usually, this view presents a map with a pin which corresponds to the location of either the drop-off or pickup. Besides this visual data on the location, the page shows a form with all the information regarding the delivery. In this window, DelivAR can operate by tapping on the round green button. Moreover, instructions on how to use DelivAR can be found at the bottom of the card.

The student designed the third screen (see fig. 3.2), showing how delivAR will possibly look once initiated. This view appears after the courier clicks on the AR camera button in the overview page. The order ID from Airmee's system will be connected to a specific fiducial marker. Once it is recognized by the phone, a 3D object on top of the target will appear. Further information and a navigation arrow allow the user to understand more the tool and browse within the app.

Figure 3.2: DelivAR camera view (mockup).

Chapter 4

Implementation

This paper is designed to investigate the opportunities, benefits, and limitations that augmented reality could bring in last-mile deliveries within the logistics sector. For this reason, two studies were implemented. The first is a set of experiments with an augmented reality mobile application developed by the author. The aim is to test the technology in different conditions and to examine the issue based on hands-on experience. The second involved an in-depth interview with a courier aiming to gain insight regarding the current situation and possible future development of the technology.

4.1 AR.js

AR.js offers different ways of realizing an interactive web AR application. This open-source JavaScript library runs efficiently on smartphones older than five years at the moment of the realization of this thesis [44]. It is purely web-based and it operates on the phone's web browser, thanks to WebGL [68] and WebRTC [69]. Therefore no installation of external software is required. Technically AR.js is built by robust open-source libraries that have been focusing on 3D and Augmented Reality for many years, specifically:

- **Three.js**: the most known open-source JavaScript library used to create and display animated 3D computer graphics in a web browser [61].
- **ARToolKit**: an open-source library for the creation of Augmented Reality application that overlays virtual imagery on the real world [54].

ARToolKit is supplied as pre-built binaries for each platform and the full source code for the SDK libraries, utilities, example and documentation. Since the stable and most used version of ARToolKit is made with C/C++, few other libraries were used within the AR.js, namely emscripten and asm.js [48], in order to compile ARToolKit's programming language to JavaScript.

One last library is part of the AR.js platform: A-Frame. Built upon Three.js, this web framework is also written in JavaScript, and it is used for building virtual reality experience. However, in this case, it can be adapted to work together with the phone camera, displaying 3D object above the fiducial markers.

An example of an HTML element that combines to both A-Frame and AR.js is the custom element of the fiducial marker:

```
<a-marker preset="hiro">
```

This line of code corresponds to an implementation of AR.js that recognizes the marker by using the ARToolkit library. The Hiro, Kanji and other markers are preset targets within ARToolKit, and they will be crucial later in the development of the thesis.

Figure 4.1: The Hiro fiducial marker used in AR applications.

4.1.1 Customized Fiducial Markers

The previous paragraph gave an introduction to AR.js. Considering the markers, for example, the idea of having custom markers was initially taken into account. The fig. 4.4 shows the initial idea of customized markers designed for this thesis. AR.js also supports this feature by using Three.js.

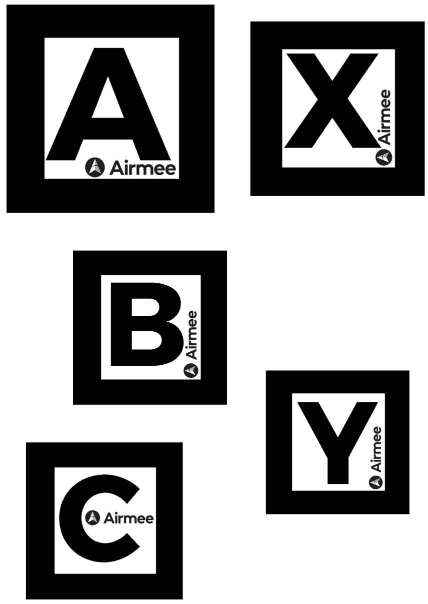


Figure 4.2: Different examples of custom markers created with the logo of Airmee.

Thus, a custom image (see fig. 4.2) made with design software is uploaded in a Marker Training [45]. The user can change the pattern ratio, which is the black square displayed around the file. Once the value is defined, the picture is available for download as PDF or standard image. More importantly, the website allows the user to download a *.patt* file. This element is a pattern file formed by a 256-character array that visually represents the design uploaded. Below an example realized with the marker with the letter A (see fig. 4.3):

255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255
255	255	255	255	255	254	0	0	0	21	255	255	255	255	255	255
255	255	255	255	255	0	0	0	0	0	255	255	255	255	255	255
255	255	255	255	255	0	0	0	0	0	160	255	255	255	255	255
255	255	255	255	17	0	0	155	0	0	0	255	255	255	255	255
255	255	255	255	0	0	0	255	0	0	0	254	255	255	255	255
255	255	255	126	0	0	3	255	7	0	0	0	255	255	255	255
255	255	255	0	0	0	254	255	255	0	0	0	255	255	255	255
255	255	244	0	0	0	255	255	255	0	0	0	6	255	255	255
255	255	0	0	0	0	0	0	0	0	0	0	0	255	255	255
255	253	0	0	0	0	0	0	0	0	0	0	0	20	255	255
255	0	0	0	2	14	14	14	14	14	7	0	0	0	255	255
255	0	0	0	254	255	255	255	255	255	255	0	0	0	238	255
5	0	0	0	255	254	254	255	255	255	255	0	0	0	0	255

Figure 4.3: Part of the *.patt* file representing the letter A.

The patt file contains the pattern and includes also the same design written in different orientations:: 90°, 180°, and 270°. The numbers show different values in terms of color range: 0 corresponds to black, and the number can increase as the color gets brighter until 255, which is equal to white.

Once the pattern is created and placed inside a repository folder, it is essential to call the file inside the code. For this purpose, AR.js has an extension of three.js that handles ARToolKit, which is the core of the all library, called *THREEx.ArToolkit*. It is composed by three classes:

- *THREEx.ArToolkitSource*: it is the source image that will be used by the application, normally would be the webcam, but it can also be a video or a picture;
- *THREEx.ArToolkitContext*: the main engine, the one that finds the marker within the image source and process the information.
- *THREEx.ArMarkerControls*: it controls the marker by using the three.js controls API [62]. It will guarantee that the 3D object is on top of the marker.

4.1.2 Prototyping with Multiple Markers

The student created different prototypes to test AR.js with different settings, experimenting on which set up would fit the requirements of DelivAR. The project strived first on building a fast and reliable application with multiple markers. The use of a custom marker was not a robust solution due to the impossibility of finding a perfect design that would be as reactive as it was for the preset fiducial markers — such as Hiro and Kanji markers. Moreover, the asset of fiducial markers included in ARToolKit was not limited to those few. The solution was using a multi-pattern of specific fiducial patterns that turned up to be the most responsive solution for this thesis. The result was a multi-pattern file that would offer up to 12 markers — ARToolkit can run up to 48 preset markers, but being an early stage project, the student decided to dismiss the solution with more targets.

The solution for the displayed object was by using 3D forms, the mentioned figures covered the entire marker and were easy to recognize, even from a far distance. The two prototypes made

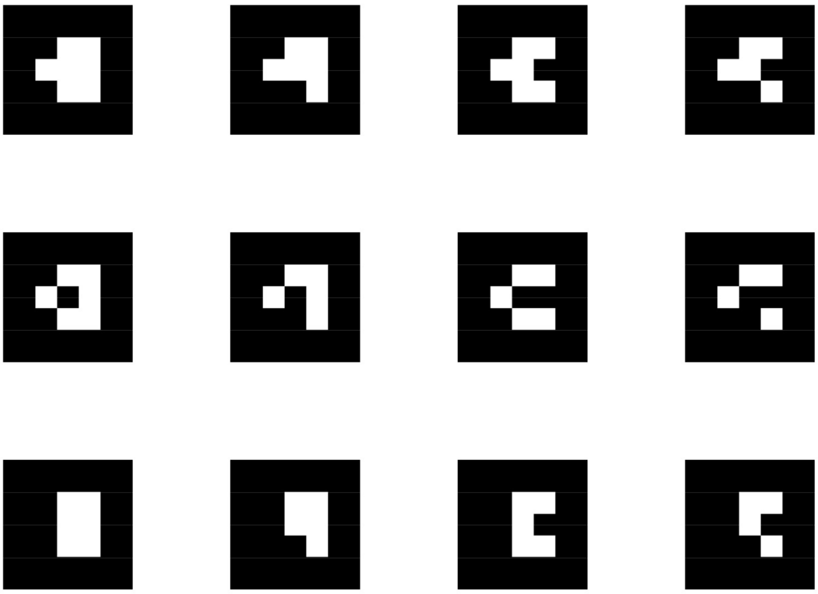


Figure 4.4: The 12 fiducial markers used in this project to test AR.js.

with 3D objects were with spheres and cubes, in both setup also the logo of Airmee in order to have a more customized app, and in the first (fig. 4.5 (a)) solution spheres were designed. Additionally, an animation was added to test the performance, which happened to slow down the loading time of the figures once the camera of the smartphone tracked the markers. More stable and reactive the other solution with cubes. (fig. 4.5 (b)) All the tests were carried out by using Apple iPhone 5S with browser Safari. The repository of the first implementation was updated online on the website `http://test.airmee.com`

(a) 3 spheres and animated logo.

(b) 12 cubes solution and static logo.

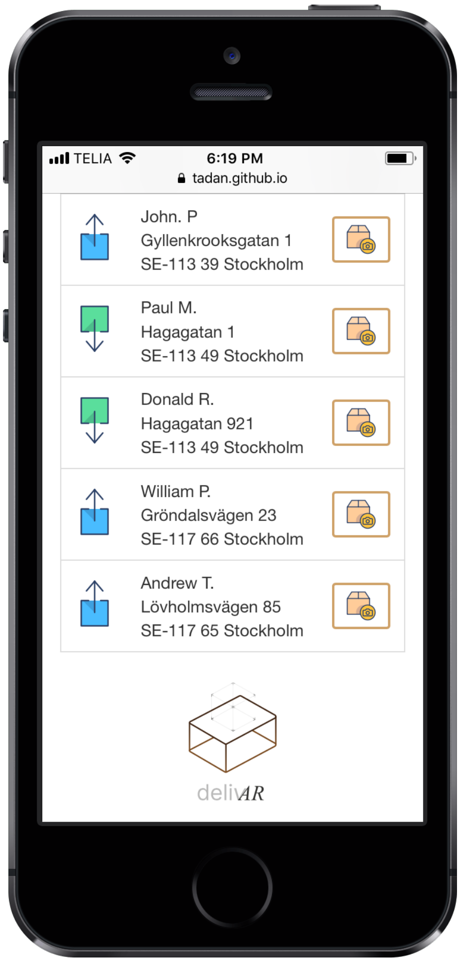
Figure 4.5: The AR application showing 3D objects.

4.2 DelivAR app

After developing different prototypes and solutions, the student decided to use AR.js with the library A-Frame for the creation of DelivAR. The application created with this final setup has two views. The first is an overview of the possible orders (see fig. 4.6 (a)) with pickups and dropoffs labeled with different icons. The second view is delivAR camera view with the 3D object displayed over the fiducial marker together with the identification time, measured in milliseconds (see fig. 4.6 (b)).

As previously explained, it is possible to use custom or more complex images as tracking objects but this fiducial marker, called 2D barcode, is easily recognizable and therefore, faster than customized targets.

Technically, it is important to mention how the logic for the identification time has been built. By using jQuery, the student created a timer which would start only when the script is initialized and stopped when the marker is recognized. The code snippet is showed at the end of this paragraph:



(a) List of dropoffs and pickups in the app.

(b) delivAR camera.

Figure 4.6: Two views of DelivAR.

```
var methods = {};
methods.checkVisibility = function (element, options) {
  element.object3D = {}
  element.object3D.visible = element[0].object3D.visible;
      if (jQuery.contains(document, element[0])) {
          var previousVisibility = options.previousVisibility;
          var isVisible = element.object3D.visible;
          options.previousVisibility = isVisible;
    var initialLoad = previousVisibility == null
          if (initialLoad) {
              if (options.runOnLoad) {
                  options.callback(element, isVisible, initialLoad);
```

```
            }

        } else if (previousVisibility !== isVisible) {

    if (!previousVisibility) {

      var identificationStop = new Date();

      var timeToIdentify = identificationStop.getTime() - identificationStart.getTime();

                  document.querySelector("#recTime").innerHTML = timeToIdentify;

    } else identificationStart = new Date();

            options.callback(element, isVisible, initialLoad);

        }

        setTimeout(function()

        {

            methods.checkVisibility(element, options);

        },

        options.frequency);

    }};
```

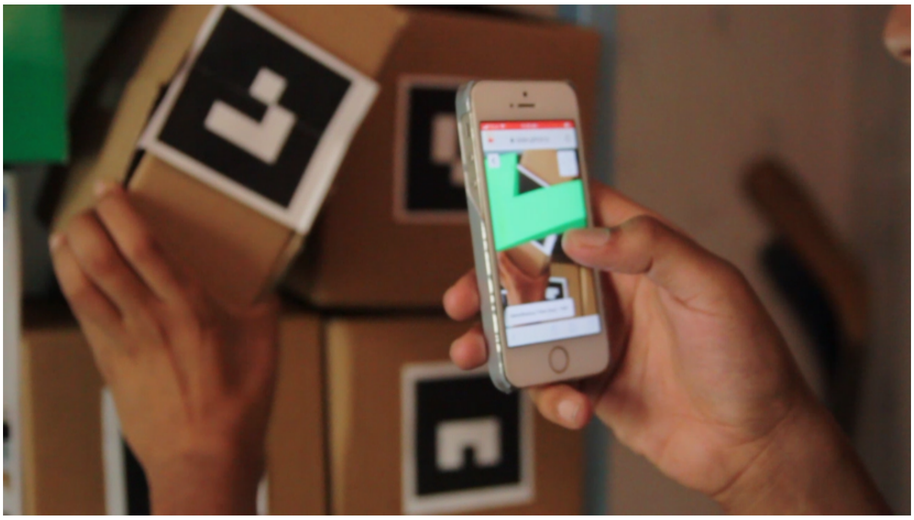


Figure 4.7: Test of DelivAR

4.3 Expert Interview

This part describes how the Semi-Structured Interview with the courier has been implemented. The general aim of this qualitative analysis is first to encourage the respondent to talk at some length and in their way. In this particular moment, the researcher has to structure the central questions around critical features, such as prompts and probes. They are used to encourage the interviewee to answer and to ensure that the person says as much as they can or wish to.

For this matter, the student decided to divide the interview into four main sections for more clarity, specifically:

- *Introduction/Final observations of the subject*: the individual generally introduces his profile and at the end speaks freely about the experience;
- *Discussion about the work*: description of what is the last-mile delivery business from the courier's point of view, work structure, etc.;
- *Showcasing the app the courier is using*: the professional shows the interviewer how the company mobile application works during all the steps: giving feedback on each page, functionality, etc.;
- *Introducing AR and testing the AR application*: the interviewer presents the concept of AR, and consequentially DelivAR is showcased. Thus the courier tries the app out, giving feedback especially in the functionality and its possible implementation;

Another aspect that is part of SSI is the possibility of controlling the type of questions used. Closed questions offer little scope in answering, and assert the interviewer's control, whereas open questions provide a wide range of choices. Besides the topic of the discussion, the student listed some guidelines that he tried to respect during the interview with the logistics expert:

- it is a formal encounter on an agreed subject, and "on the record". Specifically the main topics covered: user interface, scanning and the usability of an augmented reality mobile application;
- the interviewer sets main questions for the subject, creating the overall structure described in an interview plan;
- prompts and probes fill the structure of the interview: prompts by encouraging broad coverage, probes by exploring answers in depth;
- there will be a mixture of open and closed questions;

- the respondent has a fair degree of freedom: what to talk about especially in the initial part of the interview, how much to say, how to express it;
- the interviewer can assert control when necessary.

Chapter 5

Evaluation

This section of the thesis consists of presenting the research questions and then discussing their evaluation. How was the experiment arranged? What method was used to examine the results? The technical study implemented in this thesis consists on repeating the same process several times for each technique presented in the procedure, aiming to test the application with different light conditions, various smartphone camera resolution, and also analyzing the distances from the markers. Moreover, in this section the results of the expert interview are addressed, giving an additional overview of the future possibilities of AR applications in logistics.

5.1 Research Questions

This thesis was conducted to evaluate the following research questions:

RQ1: Which distance, light and smartphone are ideal for valid employment of the DelivAR tool?

RQ2: How would an expert sense a possible AR application implemented in his work?

5.2 Setup

After developing and testing the AR tool, an experiment is implemented by testing the tool in different environmental conditions. For this study, the student built a setup formed by a shelf full of boxes covered by different fiducial markers. This system attempts to simulate the trunk of the courier car.

Figure 5.1: Experiment Setup.

For the light test, artificial lamps are placed inside the environment, utilized during the nighttime with the complete absence of daylight.

5.3 Procedure

The student ran the technical analysis in different environmental settings with four smartphones. The approach combines the methods used in the past by Khan [18] and mentioned in the related work. These procedures focus on analyzing:

- Light intensity of the environment
- Distance and angle from the target
- Camera resolution of the smartphone

Even if the DelivAR application can analyze different fiducial markers, the student decided to run the experiment by tracking only one fiducial marker (see fig. 5.2) of the size of 8,5 x 8,5 cm, aiming at uniform measurements amid the different setups. Further analysis on the marker size are discussed at the end of this chapter. The method consisted of starting the app in a particular position and angle from the marker and collect the identification time that was displayed on the screen of the smartphone at the moment the program found the marker. The data collected in this experiment has milliseconds as the unit. Each measurement is taken fifteen times for each specific position, light condition, and model of smartphone (see fig. 5.4 and 5.6)

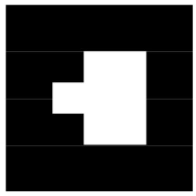


Figure 5.2: Fiducial marker chosen for the experiment.

The application of DelivAR was deployed in a Github page reachable at the following URL: `https://tadan.github.io/delivAR`

5.3.1 Light Intensity

The choice of different light conditions can be described principally in two setups: the first is with natural light, coming from a window inside the experiment room. The other measurement was done by using artificial light in a darkroom (see fig. 5.3)

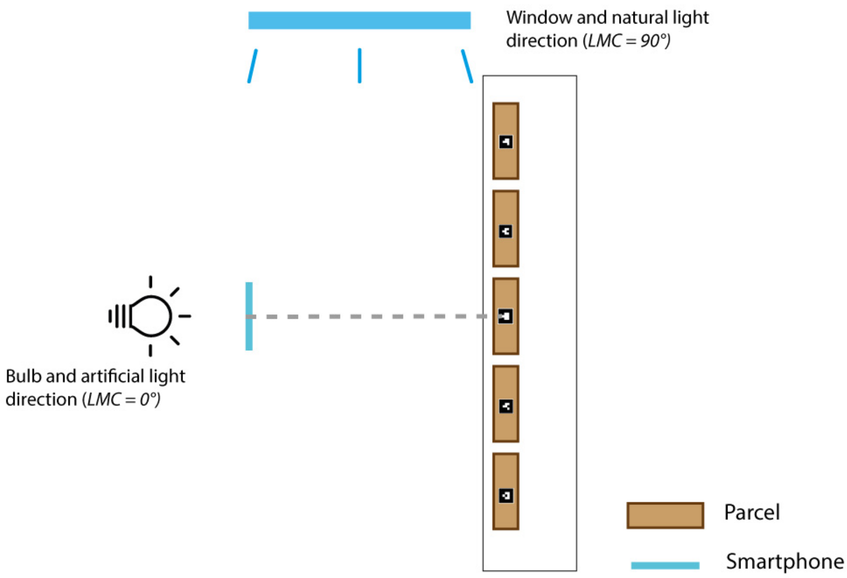


Figure 5.3: Distance and Angle from the target.

5.3.2 Distance and Angle from the target

The student has implemented this analysis by considering the Light-Marker-Camera (LMC) angle concept introduced by Khan in his research [18]. In fig. 5.4 (top-left) at the end of this chapter shows the first setup with values of LMC that change from 30 to 150 by having the natural light as the reference. In fig. 5.6 (top-left) the evaluation has been based on the artificial light condition, the measurement starts from 0 which corresponds to the smartphone aligned at the same angle as the light. Further calculations were made respectively 30 and 60 on the left and right side of the reference light position. Moreover, each angle was measured at a fixed distance from the marker of 1 meter and 1.5 meters.

5.3.3 Camera Resolution

The smartphones used in the experiment present different operative system (OS), camera resolution, overall performance and they have been produced in different moments within the past five years.

Table 5.1: Features of the four smartphones used in this thesis

Model	**OS**	**Camera resolution**	**Release Year**	**Browser**
Apple iPhone 5s	iOS 11	8 Megapixels	2013	Safari
Lenovo P2	Android 6.0	13 Megapixels	2016	Mozilla Firefox
Apple iPhone 6s	iOS 11	12 Megapixels	2015	Safari
Sony Xperia Z3	Android 5.1	20 Megapixels	2014	Mozilla Firefox

The choice of the browser was dependent mainly by the performance of the device and the compatibility with AR.js. For example on iOS only Safari is possible to use it because the *getUserMedia()* method used on AR.js works only on the standalone Safari app [55]. On the other hand, Mozilla Firefox was the choice for the Android devices.

5.4 Results

An overview of the results are shown in fig. 5.4 and 5.6 for the 1 meter camera-marker distance and fig. 5.5 and 5.7 for the 1.5 meter camera-marker distance. The combination of the figures and colors shows also the two different light setups of the experiment. The approach used to visualize the data was box-and-whisker charts. This representation shows the minimum, first quartile, third quartile, and the maximum of a set of data. Statisticians refer to this set of statistics as a five-number summary [32]. Usually, this method includes the median, yet in this evaluation, the value has been calculated and is included in the box formed by the first and third quartile to have a consistent view. The whiskers extend upward from the third quartile to the maximum recorded value, and the other extends downward from the first quartile to the minimum.

The results of the analysis on the LMC follows the Khan results which shown a consistently better performance when the marker and the camera are facing one another, regardless of the position of the light. The values are noticeable when the camera is at 90° in the daylight and 0° in the artificial light environment. The following table summarizes an example of this result, comparing the two aforementioned angles with the furthest angle measurements within 1 meter distance from the smartphone camera:

Table 5.2: Identification time (in milliseconds) of the marker at 1 meter distance using Lenovo P2

Lenovo P2 (*13 mpx*)	Daylight					Artificial Light				
Five Number Summary	30°	60°	90°	120°	150°	−60°	−30°	0°	30°	60°
Minimum	3219	1723	**2134**	2328	3228	2558	2726	**2183**	2403	3028
First Quartile	3870	2002	**2424**	2679	3620	3383	2866	**2462**	2758	3818
Medium	4293	2134	**2565**	3275	4209	5264	3282	**2530**	2922	4305
Third Quartile	5107	2537	**2860**	3761	6395	7225	3576	**2578**	3066	4581
Maximum	6983	2945	**3168**	5498	8738	10559	7154	**8101**	4581	8217

In the daylight setup, the 90° angle measurements (indicated in bold) generally present a lower or equal identification time comparing to the other angles. The difference is more relevant for the two furthest angles (30°, 150°) from the 90°: from 47% up to 175% bigger rate. However, the performance at 60° and 120° have the same or sometimes lower values of the one adopted as a reference. In the artificial setup, the measurements at the angle 0 (marked in bold) give a similar result to the daylight dataset: for the further angles (−60°, 60°) the values are 1% to 180% bigger than the reference angle, whereas similar results for −30° and 30° angles. The data from 1.5 meters measured with the Lenovo

P2 smartphone presents a similar behavior compared to the 1-meter measurements. The visible difference is the higher time that the device spent to recognize the marker, up to 3 to 4 seconds more on average compared to the previous table. The second Android phone used in this experiment, the Sony Xperia Z3, shows different outcomes that generally do not follow the Lenovo's performance. The table displays the identification times measured with the mentioned device:

Table 5.3: Identification time (in milliseconds) of the marker at 1 meter distance using Sony Xperia Z3

Sony Xperia Z3 (*20 mpx*)	Daylight					Artificial Light				
Five Number Summary	30°	60°	90°	120°	150°	−60°	−30°	0°	30°	60°
Minimum	3511	2960	**2628**	3141	3061	3220	3197	**2879**	2924	3161
First Quartile	4291	3235	**3152**	6746	3393	4257	3858	**3059**	3197	3661
Medium	4934	3876	**3488**	3749	4229	5762	4317	**3241**	3403	4122
Third Quartile	5650	4579	**4261**	4244	4997	6772	4465	**3792**	4282	4261
Maximum	7517	4777	**4503**	4704	5302	8692	4894	**4408**	4535	7143

The performance of the Sony Xperia Z3 might appear slightly slower than the Lenovo when highlighting the reference (the columns marked in bold). Although after analyzing the results, they seem more consistent with different angles and also a further distance. One of the reasons for the slower identification time can be the OS, which is Android 5.1, the previous version of the one installed in the Lenovo (Android 6.0). However, the constant performance shown in the data can provide another viewpoint on the results. In both daylight and artificial light setups, only five times the measurement shows more than 50% higher values compared to the reference angles and only one time is more than 100%. A similar outcome for the 1.5-meters distance dataset, where the device performed slower than the shorter distance but keeping the values around 3 to 5 seconds on average faster than the Lenovo. Moving to Apple devices, the first table shows the performance of the older model, the iPhone 5s with the lowest camera resolution of the mobile phones used in the experiment:

Table 5.4: Identification time (in milliseconds) of the marker at 1 meter distance using iPhone 5s

iPhone 5s (*8 mpx*)	Daylight					Artificial Light				
Five Number Summary	30°	60°	90°	120°	150°	−60°	−30°	0°	30°	60°
Minimum	1984	2026	**1985**	1932	2104	2627	1791	**1899**	2472	2682
First Quartile	2300	2240	**2318**	2154	2159	2860	2205	**2061**	2930	2934
Medium	2797	2240	**2318**	2295	2416	3097	2646	**2195**	3363	3499
Third Quartile	2993	2581	**2884**	2389	2832	3627	2972	**2377**	4169	4012
Maximum	3722	3161	**3300**	3435	3062	4457	3850	**2677**	5182	14215

The performance of the Apple iPhone 5s shows a distinctly lower identification time comparing to the Android phones. Analysing the LMC angle, the values mentioned above (90 in the daylight and 0 for the artificial light) frequently presents slightly similar numbers compared with the rest of the positions measured. In the daylight setup, for example, the data present time values 1 to 18% less than the reference LMC angle of 90 degrees. Whereas with artificial light, the measurements are reflecting the performance of the Sony Xperia Z3 with identification time 30% to 60% on average higher than the reference LMC angle of 0 degrees. The measurements from the 1.5-meters distance show an identification time of the order of 2 to 4 seconds more than the shorter distance results in the natural light conditions. However, with the artificial light, the identification time is 5 to 7 seconds higher than the 1-meter distance measures.

Table 5.5: Identification time (in milliseconds) of the marker at 1 meter distance using iPhone 6s

iPhone 6s (*12 mpx*)	Daylight					Artificial Light				
Five Number Summary	30°	60°	90°	120°	150°	−60°	−30°	0°	30°	60°
Minimum	1799	1723	**1884**	2279	1908	2059	1903	**1877**	1706	1876
First Quartile	2130	1889	**2148**	3728	2229	2399	2160	**2120**	1819	2258
Medium	2322	2015	**2270**	4496	2853	2817	2559	**2306**	2170	2915
Third Quartile	2519	2229	**2317**	5367	3664	3282	3068	**2472**	2259	3027
Maximum	3925	3449	**2868**	7304	6267	9187	4105	**3341**	3133	3699

Table 5.5 shows the dataset recorded with the iPhone 6s. The 12-megapixel-camera smartphone is surprisingly slower in performance than its predecessor — the iPhone 5s. In daylight conditions, the LMC angles at 120° and 150° present much higher values of the reference LMC angle (bolded in the table) at 90°, with timing up to 154% higher. Whereas at 30° and 60° LMC angle the results are even lower than the reference, up to 12% faster identification time. In artificial light setup, the identification time calculated at −60° and −30° is generally slower than the reference LMC angle at 0°, whereas quicker recognition happens at 30° and 60° with up to 15% faster timing. The results at 1.5-meters distance with iPhone 6s present an overall slower performance than the shorter distance measurement. The identification time is from 2 to 4 seconds slower in both daylight and artificial light conditions. Considerably longer recognition time for the LMC angles at 150° for daylight and both −60° and 60° for artificial light conditions. DelivAR recorded up to 10 seconds slower performance in those positions.

5.5 Discussion

This part of the paper answers to one of the research question posed at the beginning of the chapter. The technical analysis ran in this thesis shows a consistent performance of the DelivAR tool during the evaluation process.

This application performed uniformly with different marker sizes. The targets — printed and tested in different dimensions (see fig. 5.4) — did not make differences in the execution of the tool within the range of distances initially set. Only with a distance of 1,5 meters from the target, in few cases, a more prominent marker would have been recognized faster by the camera. Therefore, the final choice was an 8,5 x 8,5 cm marker that would fit one side of the box used for the experiment.

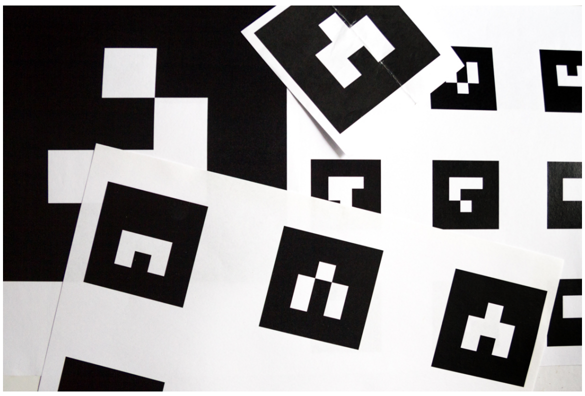


Figure 5.4: Different marker sizes tested in the experiment

The light condition study shows a similarity between daylight and artificial light setup. Therefore, the result does not point to a solid conclusion to which light source is more suitable for this AR application. However, the app lacks in performance when a direct light covers the fiducial marker. This effect is due to the reflections occurring on the paper where the fiducial marker is printed. Thus the camera of the phone could not recognize the target, especially for greater distances than one meter.

The LMC angle analysis confirmed the hypothesis mentioned in the procedure: a faster identification time occurred when the camera and the marker are facing one another. In this thesis, the settings correspond to 90° angle for daylight and 0° for the artificial light conditions. However, the performance of the iPhone 5s has been consistent in most of the angles when operating in daylight conditions. Moreover, the performance of the DelivAR tool showed the slowest recognition time when performing at 150° angle for the daylight and 60° for the artificial light. In this cases, the application reacted by 50% up to 110% slower compared to the reference angles in the respective light conditions considering the medium time value.

The smartphones used in this investigation responded similarly during the evaluation process, yet the Apple devices were slightly more reactive on loading the DelivAR program. The iOS devices registered 1 second (on average) faster recognition time than the Android phones. Specifically, the 8-megapixel-camera iPhone 5s in most of the cases was faster than any other smartphone, not only to its upgraded version, the iPhone 6s. The 20-megapixel-camera-resolution of the Sony Xperia Z3 had a prompt identification time, similar to the Apple devices. However, this result presents a bias: the slower loading time of the program due to the old generation of Android operative system installed in the Sony. Hence, it is difficult to make a comparison among the phones camera resolution without considering the AR app loading time. A case that was not covered by this work is an extensive analysis of the false identification. This error was visible mainly on measurements at 1.5-meters distance from the target. The student made an approximation of this value by 10% to 20% on the Apple devices and 20% to 30% on the Android smartphones.

5.6 Semi-Structured Interview with a Courier

The related work chapter highlights the need to further support the technical analysis of this thesis by performing a semi-structured interview (SSI). The outcome of this study will help the student to answer the second research question of this thesis. The qualitative analysis was carried out with an expert courier of Airmee, a 31-years-old man who has been with the company since its foundation in 2016. Before that time, the courier worked for five years in PostNord, the state-owned logistics company in Sweden. The working tools used in that time by the expert were initially a paper list and later a specific device for couriers. The interview, as previously mentioned in the implementation chapter, encouraged first a general discussion about his job and how the driver uses the mobile application in his work. In the last part of the conversation, the expert tested DelivAR after a short introduction to augmented reality.

Since the interviewed professional gained more experience than his colleagues, he partly works in the warehouse organizing the tasks. The remaining time is dedicated to deliveries that reach the final receivers. The time span he usually operates is from 4 pm to 10 pm every day, weekends included. Once the tasks are arranged in the warehouse, the courier drives loaded with parcels to clients with one of the companys vans. The work process is mainly carried by the Airmee app installed on his smartphone. The courier can drive directly to the destination without using an external app or other devices. The courier highlighted the smartphone as the first difference with postmans working tool. His previous work placement involved a paper list and a dedicated device. Another contrast regarding the operation strategy between last mile and regular delivery service is heading towards the drop-off methodology. At the moment of the interview, the courier did have the priority to deliver the food boxes first and the rest of the packages later. Another difference is that last-mile delivery services cannot avoid in-person interactions with the receiver. Therefore, when the receiver is not at home, the delivery can be postponed.

After this introduction, the interviewee was asked to explain how he uses the company's app on his device. The application runs on Android, and it works with geolocation services. This feature, once activated, notifies the system that the courier has started his work. Consequentially, the Airmee's algorithm behind the app elaborates the information about the location, time and traffic and informs the final receiver of the delivery time. Thus the courier gets a sorted list of the orders that will be delivered progressively. Each order, once the delivery process has started, presents various pieces of information about the destination, such as the name on the door, knock or ring, floor etc The courier describes this part as the most difficult of the entire delivery process due to the difficulties of finding the right address or the house number. Not only the interviewee showed all possible features that the app supports but also he highlighted several different scenarios that a courier can face during the delivery process, such as postpone, cancel, delay, receiver refusing the parcel, etc. In the final stage of the drop-off, the smartphone is used again to confirm the success of the delivery, either with a photo of the package in its final destination or with a signature of the receiver, drew directly on the display of the device. Regarding the package, the dimension of the parcel is visible in the overview page, yet no information appears in the app about the position of the item inside the car. The procedure suggested by the respondent to speed up this process is to find a correlation between the retailer name or logo shown in the app and its corresponding design on the package. Although due to the high number of parcels inside the car, this solution might not always be convenient. Generally, the courier appears satisfied with the app, it shows enough information, including the integration with most of the services he uses for his role every day.

At that point, the interviewer presented the concept of AR and the idea of DelivAR. Initially, the definition was not familiar to the worker. Albeit after the student explained few examples of recent applications made with AR, the courier declared that he has been using AR before via social networks. The examples he mentioned were the camera filter features present in Snapchat, Instagram, and Facebook standalone apps. The interviewer asked the courier to take his phone and start using DelivAR, explaining which are the basic functionalities of the app. After he was familiar with the first view of the app, showing the order list, the interviewer asked the respondent to try the camera of the app on sample fiducial markers displayed on a screen. The reaction of the courier was initially positive, firstly because the application was running in his smartphone browser without installing any external application.

After using the app briefly, the courier seems generally confident with the program, trying different fiducial markers and describing the process to the interviewer. Ultimately, he shared a possible limitation of this tool to the student. The number and most important the position of the packages inside the car might affect the performance of DelivAR. Some parcels will be on top of other ones, eventually hiding their fiducial markers and the application will have some constraints on its recognition process. The interviewee makes an approximation of forty packages as a possible limit for this app to work correctly. The estimate considers the capacity of a mid-size truck that the courier usually drives.

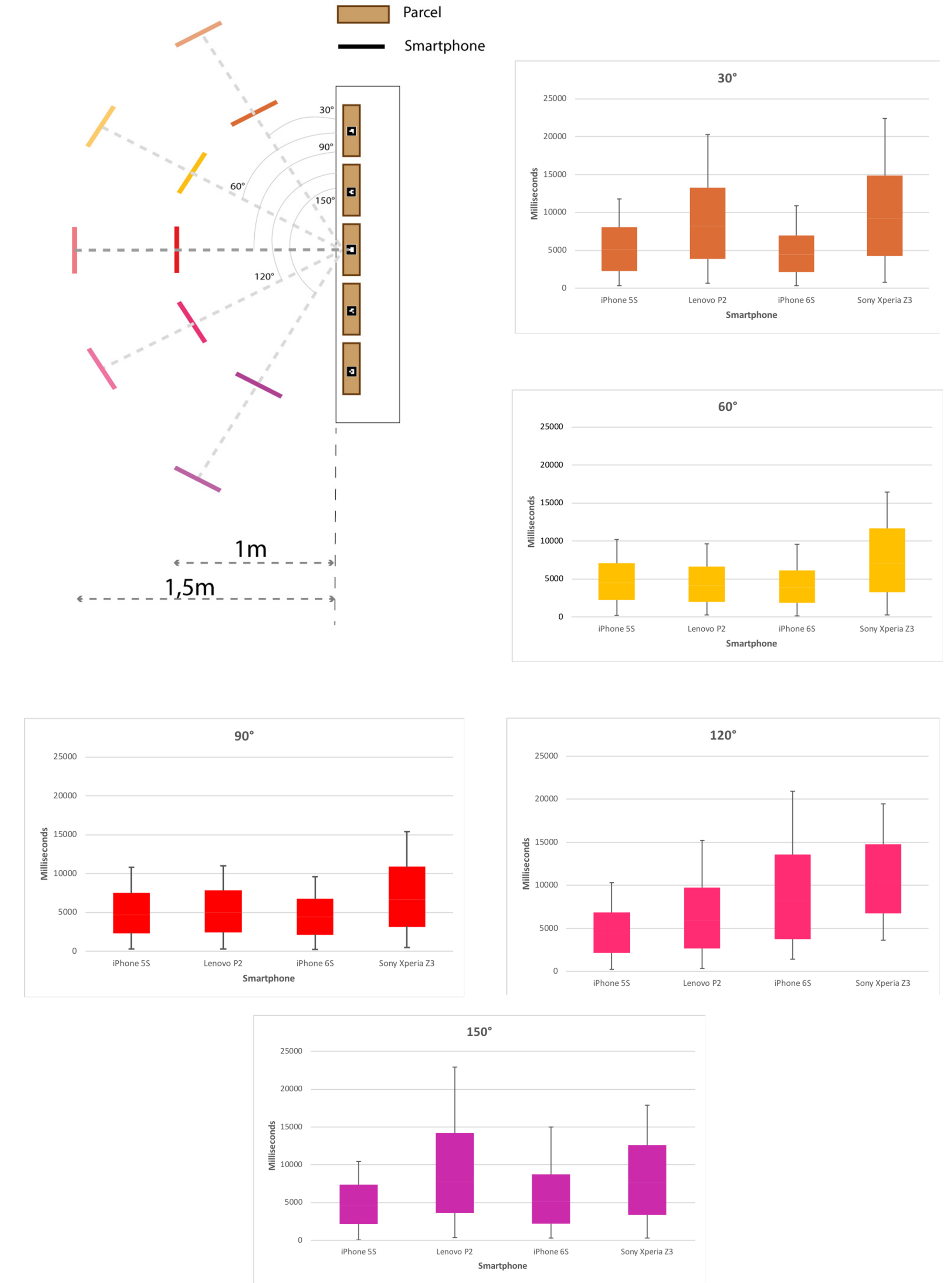


Figure 5.5: Setup of the measurements done in daylight condition (top-left) and results at 1 meter distance.

Figure 5.6: Measurements done in daylight condition at 1.5 meter distance.

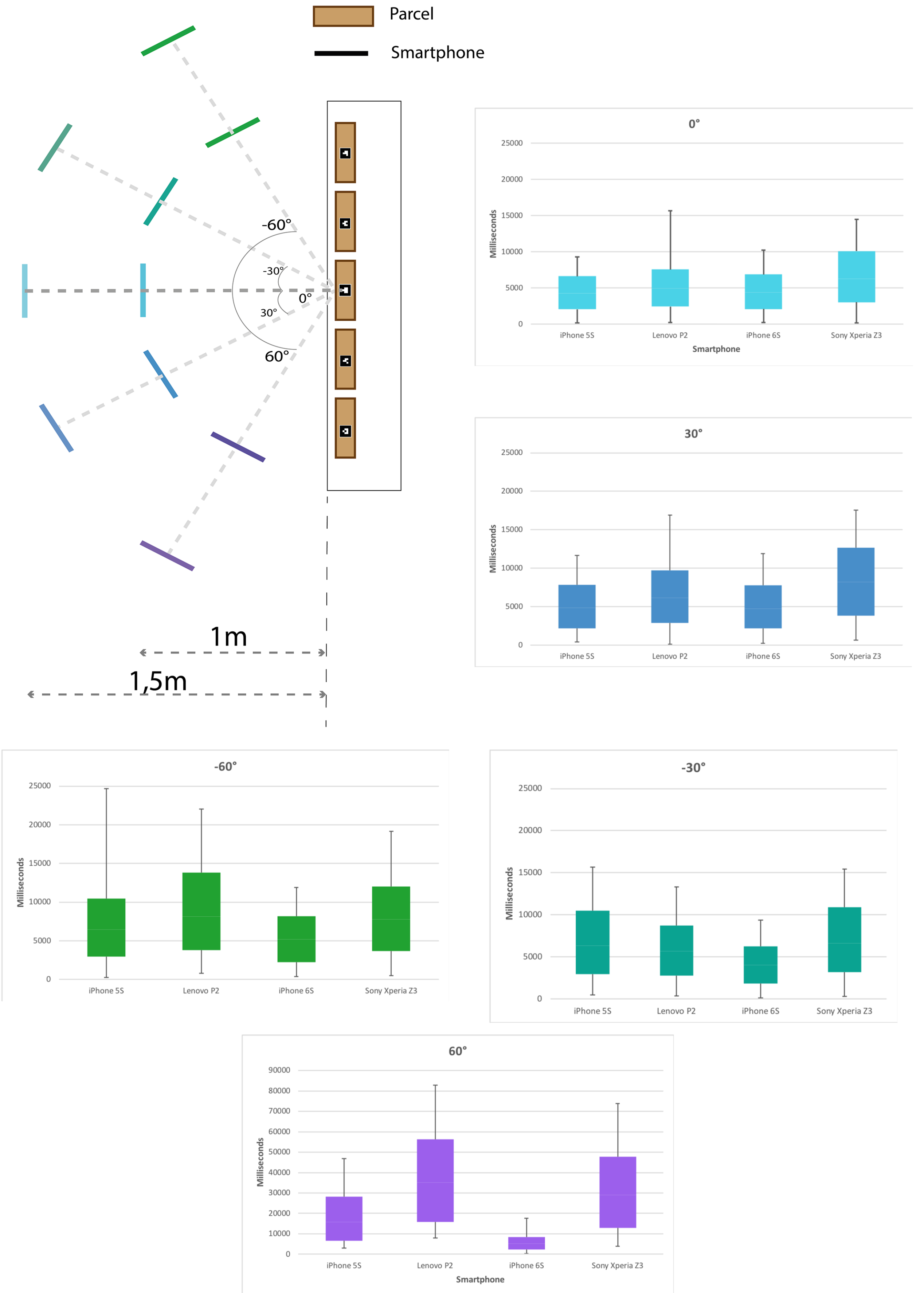


Figure 5.7: Setup of the measurements done in artificial light condition (top-left) and results at 1 meter distance.

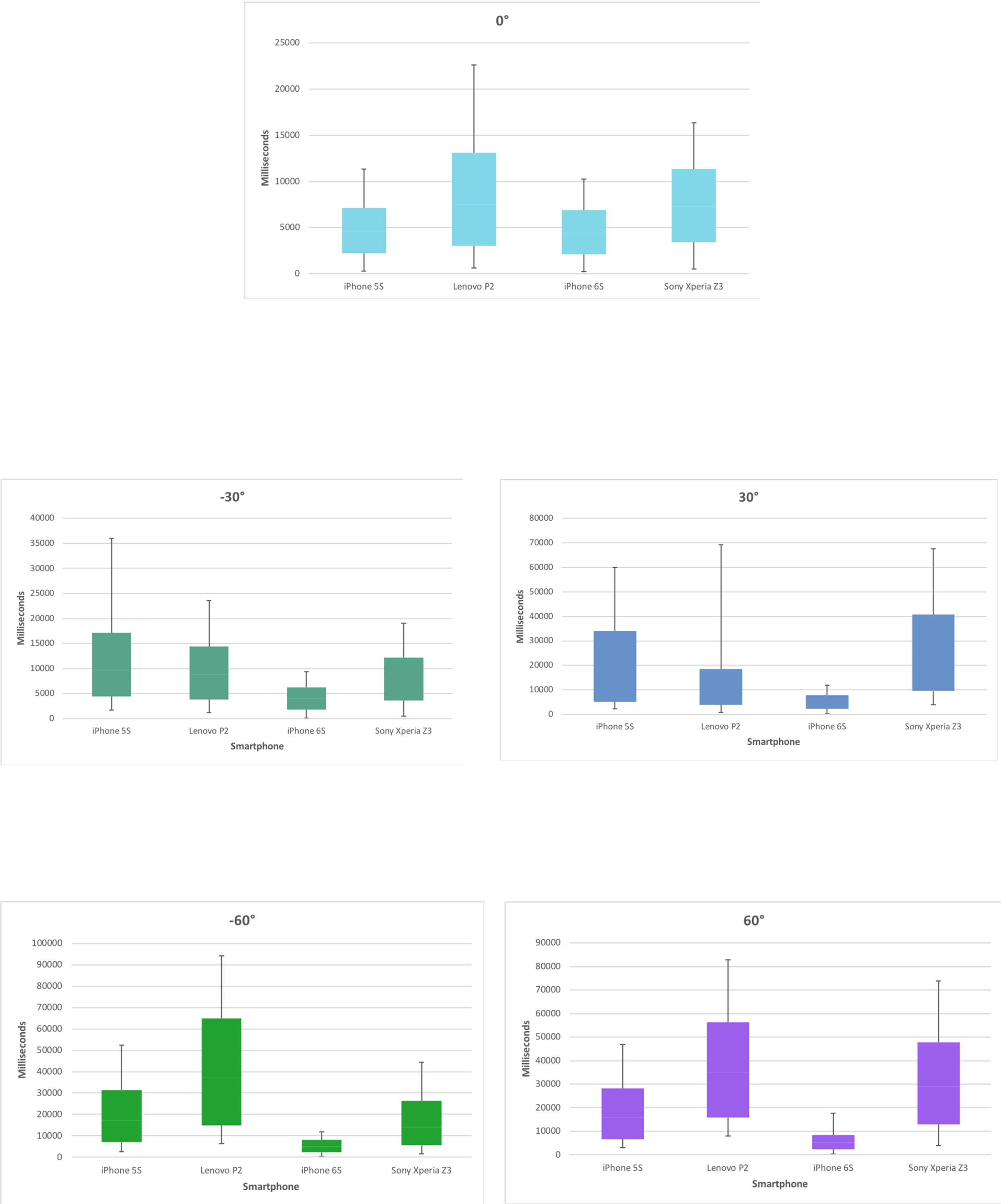


Figure 5.8: Measurements done in artificial light condition at 1.5 meter distance.

Chapter 6

Conclusion

Augmented Reality (AR) has the potential to improve some of the logistics operations, helping in particular last-mile delivery professionals. The couriers, for instance, are gradually becoming more confident in using smartphones and apps for their daily tasks. Thus, AR can be developed as an integration of the mobile app dedicated to logistics operations.

In this study, the AR features performed remarkably well on both Android and Apple devices. Even with old phones and low camera resolutions. In the technical test, DelivAR performed with light conditions that were ideal, in both daylight and artificial light setups. Therefore, further analysis simulating different light settings — ideally inside a courier car — can eventually improve this tool in future investigations. The arrangement of the packages inside the van would also be a new study for the future. The experiment setup aimed to investigate the efficiency of the AR tool rather than simulating a real scenario.

Furthermore, the technical analysis revealed that different Light-Marker-Camera (LMC) angle could decrease the performance of DelivAR. The study proved a fast identification time when the marker and the phone camera are facing one another. The identification measurements were around 2,5 seconds on average, including the app loading time. From different angles, the recognition time becomes 30% to 50% slower. Also, false identification is likely to happen when the camera is more distant than one meter from the fiducial marker.

On the other hand, the qualitative analysis performed with the expert proposed valuable outcomes. It revealed how the interactions with smartphone became actively part of the driver work. The courier was able to show and interact seamlessly with his phone while answering questions and explaining his work responsibilities. After the AR concept was introduced, the expert ran the DelivAR app on his smartphone, and he was able to use the tool without impediment. The opinion made by the professional from the use of the application pointed to its possible employment. The courier states that during the driving time — or in the loading process — the arrangement of the boxes might change, and possibly hiding the markers. Thus, the recognition will not occur and this situation can limitate DelivAR.

This thesis confirms that AR can gradually advance part of the logistics industry due to its practical application. The identification of package can be supported by an AR tool. Future development of DelivAR could combine features from the courier app and include new AR advancements. Even though AR would possibly slow down trained workers, it could still prevent careless mistakes. The smartphone, a device already adopted by the couriers, can run AR application flawless, even without the most recent smartphone. Furthermore, the professionals will not work with a different device, and they would not need to get specific training for this AR program. Hence, DelivAR can be supportive of couriers operations within the frame of their smartphones, a solution that can possibly drive changes in the last-mile delivery market.

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