3D FURNITURE PLACEMENT AND CUSTOMIZATION IN MARKERLESS AUGMENTED REALITY

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Dissertation submitted in partial fulfillment of the requirements for the
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DECLARATION

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Name: Mr. Udara Samaratunge

Signature of the supervisor

Date:

ABSTRACT

Designing and marketing of furniture according to the exact requirements of the customer has always been a pending problem in the furniture industry. Customers who purchase furniture from the dealer have to wait till the furniture arrives at the location in order to check if that product matches with the expectation they had when purchasing it. The customer gets dissatisfy with the purchased product due to the colors, design or scale not suiting the location where they want it to be placed.

This research study is focused on studying a newly emerging technology called Markerless Augmented Reality, its techniques used in the present date and selecting an efficient technique in order to develop a system comprising of a mobile application which utilizes Markerless Augmented Reality to place 3D models of the furniture to non-predefined environments. Unity 3D – Game Engine is used for development and the mobile application is created for Android operation system.

In the age where Augmented Reality applications are expeditiously taking hold of the market, this study looks into ways of utilizing the said technology to overcome a pending problem in the furniture marketing industry. What methods are currently used for Augmented Reality applications? What are the possible solutions for mobile marker-less augmented reality? How will this solution help to improve the furniture market? These are some of the questions answered in the pages that follow.

Keywords: Augmented Reality, Markerless Augmented Reality, Unity 3D, game Engine, Android operating system

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LIST OF ABBREVIATIONS

Abbreviation	Description
AR	Augmented Reality
SLAM	Simultaneous Localization and Mapping
PTAM	Parallel Tracking and Mapping
DTAM	Depth Tracking and Mapping
SDK	Software Development Kit
IDE	Integrated Development Environment
KB	Kilo-Bytes
API	Application Programming Interface
DoF	Degrees of Freedom
RAM	Random Access Memory
GHz	Giga-Hertz
Mbps	Megabits per second
MB	Mega-Bytes

1 INTRODUCTION

1.1 Background Context

With the introduction of Augmented Reality and its two main categories namely Marker-based Augmented Reality and Markerless Augmented Reality into the mobile application industry, a new perspective has been opened for innovative marketing techniques. Marketing industries are slowly immersing themselves in this technology in order to provide their customers a new level of satisfaction. Although a number of marker-based augmented reality applications are currently available, applications developed with marker-less augmented reality technology are small in number as a result of novelty and highly evolutionary nature of the AR technology.

Under this environment, it would be a good opportunity to study whether augmented reality can be utilized by any means in the furniture marketing industry to provide improvements for the current marketing methods used. "Markless Furniture" is an application developed by the knowledge gained through this research study.

1.2 Research Gap

Sri Lanka is lacking behind in providing a better customer satisfactory solution for furniture marketing. Several types of research have been carried out in fields related to similar problem domain but no practical solution was proposed as of yet. When considering Augmented Reality, solutions proposed were based on marker-based AR which uses predefined markers (An image or pattern of the real world pre-stored in a database) which can be detected in the real world and on which augmented 3D objects are displayed. This use of marker-based AR limited the user to the prior mentioned predefined markers, as the mobile devices have to detect the markers in order for the augmented reality to work and will always have to be focused on the marker for continuous augmentation. As a general mobile phone's camera capability is limited therefore the user is restricted to operate the application only in the vicinity where the marker is visible. To overcome this obstacle marker-less augmented reality was introduced. Markerless AR used image processing techniques similar to the marker-based AR but in this instant, it does not detect markers, hence the name marker-less. Markerless AR detects and identify the real world itself and calculate the position of, this in-turn tackles the operational range limitation of marker-based AR. The next issue which arises in this methodology is the weight of said calculations and image processing that need to be done. Once again as a mobile phone's processing capabilities and camera specification limitations the current solutions which are offered by markerless AR lack the reliability and support necessary to be used in mobile applications.

1.3 Research Problem

Furniture manufacture is a vast industry with countless variations in implementation methods and designs. This variation of designs make the marketing of products very complex and cumbersome. Furniture manufacture is a large sub-sector within the industries in Sri Lanka. Household furniture is made to look strikingly elegant and comfortable to use. This includes but not limited to furniture for the bedroom and living room, kitchen furniture.

The marketing aspect of the furniture industry continuously faces a strenuous task of satisfying the customers' demand. Designing furniture according to the exact requirements of the customer has always been a pending problem in the furniture manufacturing industry. Customers who also purchase ready-made furniture will not know if the selected furniture actually meet their expectation till those mentioned products are brought and placed in their specific location. If they are not satisfied with the furniture they will either refund it or if it cannot be refunded, will have to make do with it. This results in customer dissatisfaction as well as the decline of marketability for products.

1.4 Research objectives

1.4.1 Main Objectives

Project “Markless Furniture” main objective is to provide an augmented reality mobile application for customers of the furniture market, to help them preview the products they wish to purchase at their location beforehand, in-turn increasing both customer and dealer satisfaction.

1.4.2 Specific Objectives

1. To identify current and best marker-less augmented reality technology which are functional in a wide range of mobile phones.
2. To determine solutions for any limitations that are been imposed by the selected technology and operating devices.
3. To implement a means of furniture augmentation with chosen technology from selected marker-less AR technologies.
4. To implement a solution for customers to easily operate augmented reality features while allowing the freedom to move around the augmented furniture.
5. To find a means to allow customers to augmented several objects at once and to customize them with the options provided by the furniture dealer.

2 LITERATURE SURVEY

In this literature survey, the first section will provide a definition for the term "Augmented Reality". Then the next section will review "The Markerless Augmented Reality". Finally, "Current Mobile Augmented Reality technologies" will be defined with the help of literature.

2.1 Working Definition for Augmented Reality

What is augmented reality? An Augmented Reality (AR) system supplements the real world with virtual (computer-generated) objects that appear to coexist in the same space as the real world. [1] While many researchers broaden the definition of AR beyond this [2], It can be mainly defined that AR system to have the following properties:

- Combines real and virtual objects in a real environment;
- runs interactively, and in real-time;
- Registers (aligns) real and virtual objects with each other.

Although the term Augmented Reality dates back to the early 1990s, the first fully operational and functional AR system originated in the late 1960s [2]. From there onwards AR has been constantly improved and now with the increase of computation capabilities of the portable device, making its way into it.

2.2 The Markerless Augmented Reality

The present Augmented Reality Technology can be divided into two distinct fields of study as; Marker-based Augmented Reality and Markerless Augmented Reality. The field of marker-based Augmented Reality relies upon a predefined target "Markers" [3] (A real-world image or Pattern) onto which digital images are augmented. The figure 2.2.1 shows a demonstration of how Marker-based AR operation, the top middle of the image show a picture of a pattern – A Marker and the two lower images show off how the device detect that pattern and augment a 3D object of a cube top of it. The figure 2.2.1 also depict how viewing the marker from different angles affect the orientation of the augmented 3D object.

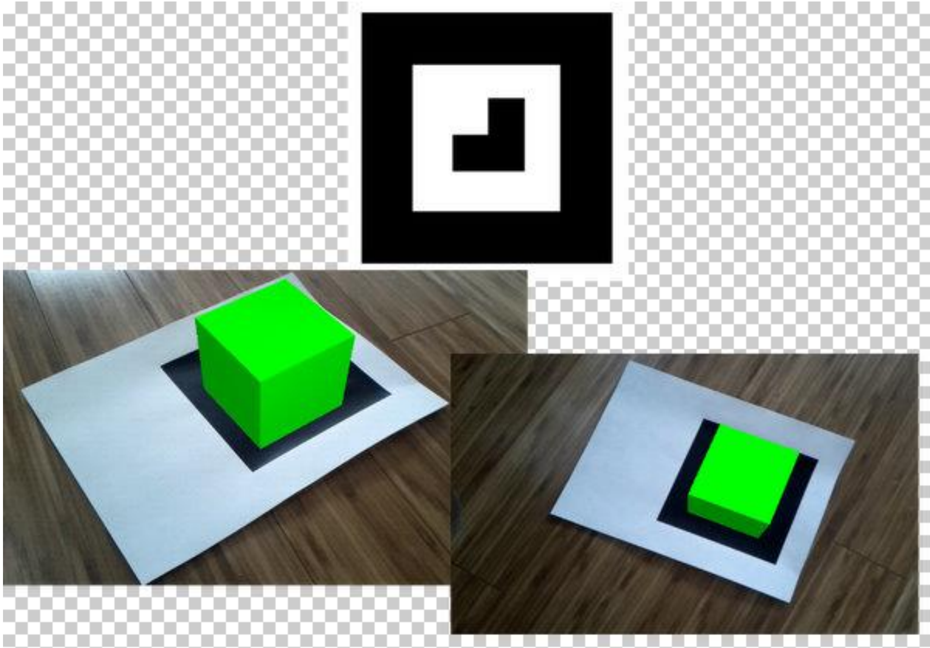

Figure 2.2.1 Marker-based augmented reality example
Source: http://code.tutsplus.com/tutorials/augmented-reality-getting-started-on-android--mobile-4457

The Markerless Augmented Reality as the name itself states deviates from the prior mention field wherein this does not use “Markers”. Markerless Augmented Reality relies on tracking features [4] (distinctly identifiable location such as shapes, edges and point) of the area of the real-world retrieved on run time and data from device sensors to identify the position onto which digital images or 3D objects are augmented. Several techniques have been researched in Markerless AR [5], [6], [7] regarding how to effectively map and retrieve features for real-world. The figure 2.2.2 shows a demonstration of how Markerless AR operates. The figure’s part (a) show how the user’s hand is recognized to augment a model of the 3D coordinates onto it. Part (b) depicts how a 3D object of a kettle is placed on the uses hand without having to rely on predefined markers while two more kettles are placed on markers. Part (c) and (d) show off an augmented 3D statue of a rabbit was placed on the user’s hand and how that object follows the hand while maintaining the correct orientation. [8]

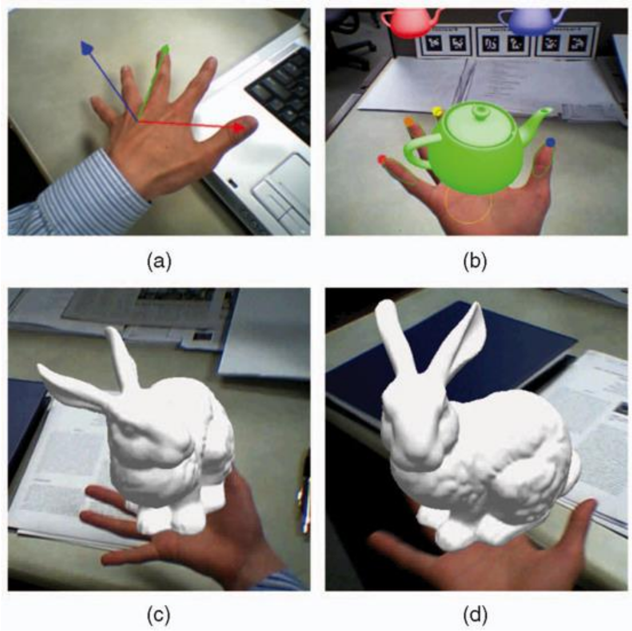

Figure 2.2.2 Example of marker-less augmented reality
Source: http://ieeexplore.ieee.org/ieee_pilot/articles/03/ttg2009030355/article.html

Simultaneous Localization and Mapping (SLAM) is an approach which was originally used in environment mapping for robotics [9], which was later improved for computer-vision based applications such as AR. SLAM is a way of building a consistent map within an unknown environment while keeping track of the current location at the same time. Several methods have been researched for achieving SLAM some of which are [5], [6], [7]. Parallel tracking and mapping (PTAM) [6] used a key-frame based Mapping framework which is PC-based, PTAM experimented on mobile platforms and have proven that it be can be used for mobile implementation but with a certain amount of limitations as stated in [6]. Figure 2.2.3 illustrates a screenshot taken when PTAM is operational.

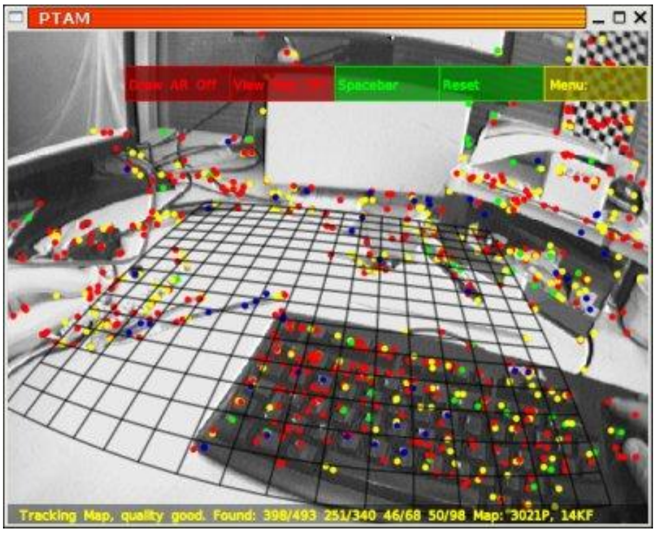

Figure 2.2.3 PTAM Operation Screenshot
Source: http://www.robots.ox.ac.uk/~gk/PTAM/

Dense tracking and mapping (DTAM)[10] is another technique which followed a couple of years after PTAM which operates on real-time to produce a dense model of the surface it recognized by tracking. This model can then be immediately used for augmentation. Figure 2.2.4 depict how DTAM and PTAM operate.

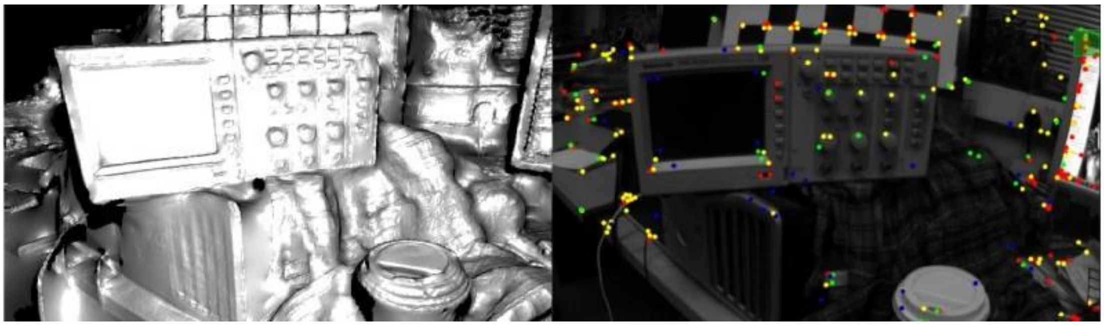

Figure 2.2.4 DTAM and PTAM
Source: http://homes.cs.washington.edu/~newcombe/papers/newcombe_etal_iccv2011.pdf

Fast-SLAM is another algorithm [7] used to tackle the issue of concurrent mapping and localization which was initially utilized in autonomous robots. This method has been proven to be operational with a small number of features making this a more favorable method to be used in mobile applications.

2.3 Current Mobile Augmented Reality Technologies

The current mobile augmented reality technologies can be categorized into the prior mentions fields of marker-based or marker-less augmented reality as shown in Table 2.3.1.

Table 2.3.1 Augmented reality categories and current technologies

Marker-based AR	Markerless AR
Kudan Augmented Reality	Kudan Augmented Reality
Wikitude	Wikitude
Vuforia	
ARToolkit	
Catchoom	
InGlobe AR Media	

Source : https://www.kudan.eu/kudan-university/look-leap-part-ii-kudan/

Through this table, it can be clearly identified that Marker-based AR consist or a large variety of solution while Markerless AR solution is quite limited.

Let us now compare and contrast the current markerless AR technologies. Starting with Wikitude. Wikitude is a mobile AR technology provider based in Salzburg, Austria, Founded in 2008, Wikitude initially focused on providing location-based AR experiences through Wikitude World Browser App. Wikitude SDK is Wikitude's core product first launched in 2008. The SDK is offered for both Android and iOS operating system. In order to achieve markerless AR Wikitude recently released Beta version of its own version of SLAM. Wikitude has developed a common core known as the 3D Tracking engine which serves as the common base for a number of use cases. (Figure 2.3.1)

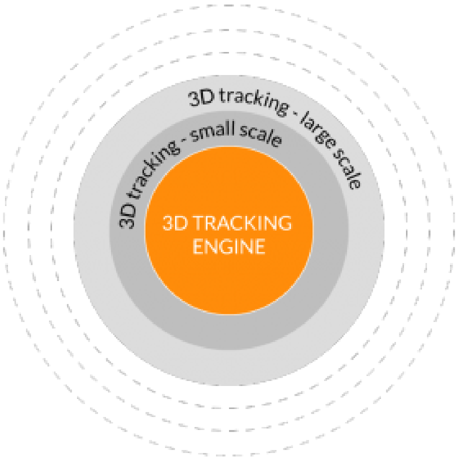

Figure 2.3.1 Wikitude's 3D tracking engine and usecases
Source: http://www.wikitude.com/blog-wikitude-large-scale-3d-tracking/

The Wikitude 3D tracking features allow to the user a 2 step mechanism where first the user needs to scan the real world environment where he wishes for the augmentation to happen and create a map of that scanned environment. The system will notify the user once it has recorded enough tracking information to produce a good quality map. (Figure 2.3.2) This map will then be saved and stored in the device so that information can then be used for marker-less augmentation. The second step of the process is to retrieve that stored map file and utilize its information in order to augment 3D objects to the real world.

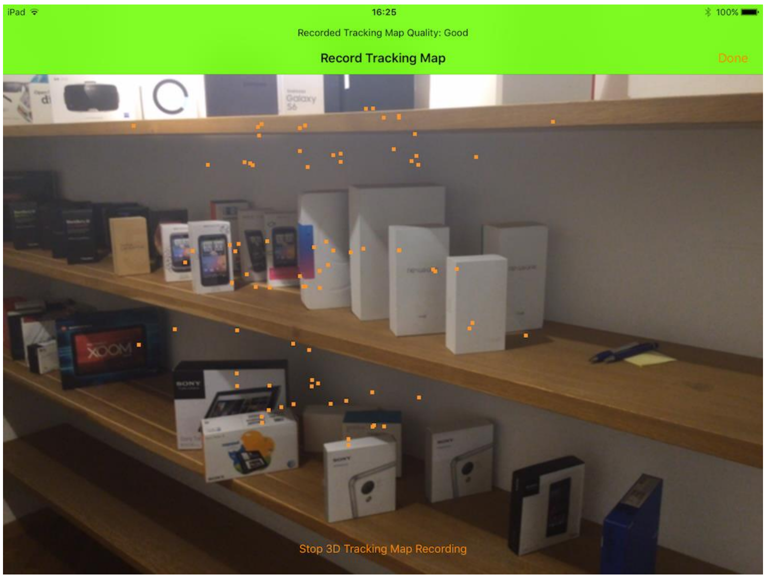

Figure 2.3.2 Wikitude record tracking map
Source: https://www.wikitude.com/external/doc/documentation/5.2/iosnative/trackingmap3d.html

Proceeding onto the next technology offer for the markerless AR category. This is a technology called “Kudan Augmented Reality”. On September 17th, 2015 – Kudan Limited, a professional Augmented Reality company based in the UK and Japan, launched an AR engine. The Kudan SDK offers the developer an easy to use robust and lightweight AR engine for development in both Android and iOS operating systems. The Technology Kudan AR SDK offers is claimed to significantly differentiator from the existing solutions. Some of the unique features of Kudan AR are,

- A built-in suite which includes a marker-based solution with no limit for the number of markers with which it can operate simultaneously as well a marker-less tracking solution (Utilizing SLAM, Arbitrary-Tracking).
- A 3D rendering engine which facilitated realistic, animated 3D model and HD video handling capability.
- The SDK has a very small footprint, allow devices with limited storage space, for example, Smart Glasses, Machine vision application and Internet of Things (IoT) sensors to utilize with ease.

For achieving augmented reality KudanAR uses its own SLAM knows as Arbitrary Tracking based on tracking for arbitrary parts of the camera image. This can be the entire camera image, including any new parts that come into view or constrained to a narrower area such as a person. It initializes instantly without requiring different viewpoints and can instantly expand to include new parts of the world.

The difference of arbitrary tracking and the conventional SLAM methods is that arbitrary tracking initializes instantly without having to first map the environment and store the information. Kudan also goes on to mentioning that it works especially well on flat surfaces such as distance landscapes, floors, or walls where other SLAM techniques are limited to close proximity operation. Arbitrary tracking also allows expanding to include new features as it comes into view of the camera. The figure 2.3.3 (a) – (c) depicts how Kudan Arbitrary tracking instantaneously initializes and how new features are taken in.

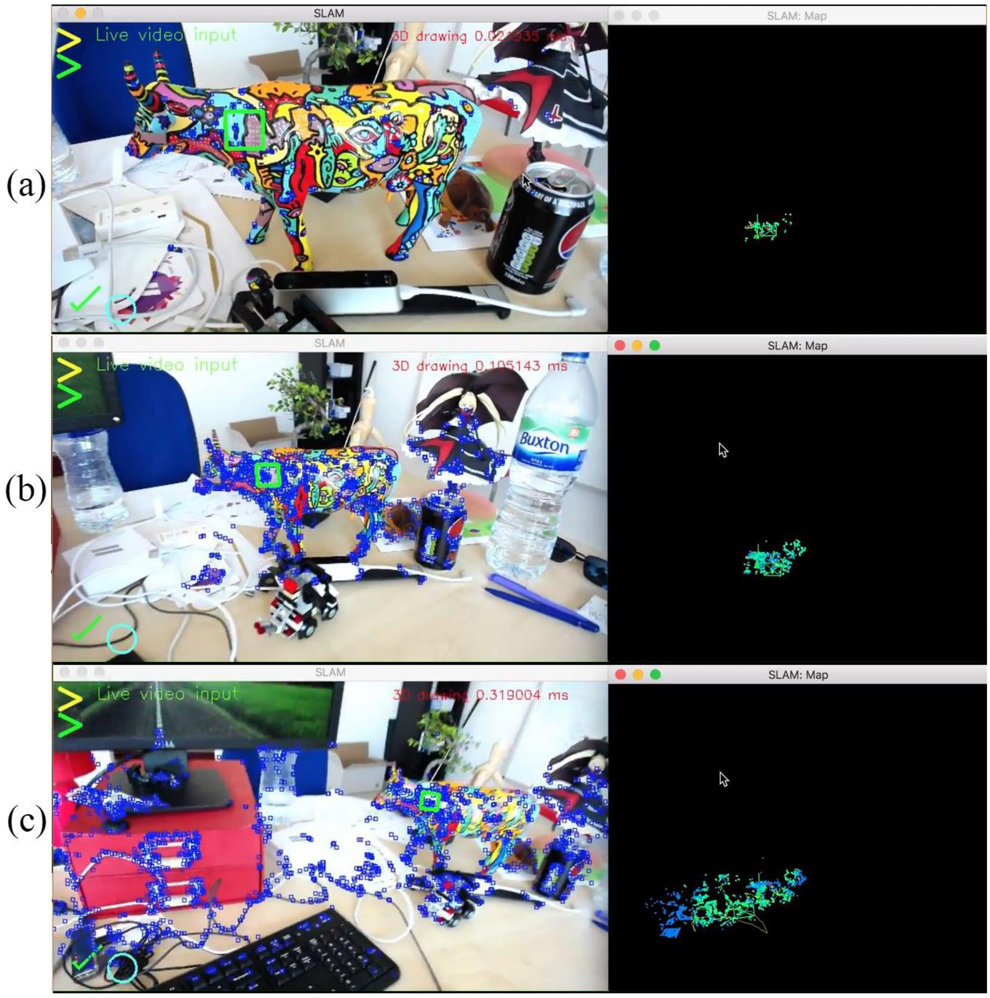

Figure 2.3.3 Kudan SLAM initialization and mapping
Source: https://www.youtube.com/watch?v=J-n4vZHAmoM

At the start only the distinct features (point in an image which can be uniquely and clearly identified) at close proximity to the point of initialization is recognized and recorded Figure 2.3.3 (a). As the user moves away from the initial location new real-world environments are revealed to the camera, this is turn is identified and the new features obtained from it is been merged with the previously recorded features. As the user travels more and more the system will continuously identify and include new features that were not present previously. This method also allows the user to directly start the augmentation of objects while the mapping process is been carried out without having to first map the environment and wait for the mapping to be completed before starting the augmentation of 3D objects onto it. This also means that as Kudan AR continuously increase the number of features that can be tracked, by which the stability of what is been augmented to the real-world environment is also increased.

Kudan AR also utilizes the gyroscope – a sensor in mobile phones which detects the orientation and provide a reference direction for navigation, to define a virtual floor plane where the device is aiming. This means that after augmenting the 3D object onto real world that 3D object's orientation is linked to the orientation of the real world. Therefore in whatever angle/orientation the user holds the mobile phone's camera the augmented object will remain in the orientation it was initialized with respect to the real-world. Figure 2.3.4 which depict a 3D model of a car on augmented on a flat floor as it is viewed in a different angle from the camera, helps to process this theory.

Figure 2.3.4 Kudan AR utilizing gyroscope for orientation
Source: https://youtu.be/vRt4L2MyHnM?t=45s

2.4 Existing AR Products relating to the Furniture Industry

This section contains a comparison of existing products in the global application market with related to the furniture industry allowing the customer to augment 3D models of furniture.

- "Sayduck" application

  Sayduck [11] is an application developed for both iOS and android devices using Vuforia [12] framework enabling the customers to try out furniture products virtually while customizing them. But the application does not support markerless AR which will be a value added service in making the customer satisfaction ratio high.

- “Augmented furniture” application

  Augmented furniture [13] is a marker-based application where the user needs to place a predefined marker in order to augment furniture in the environment. The application is mainly targeted for iOS devices leaving the majority of android users out of their sales. Even though it supports multiple furniture item placements in the augmented environment it does not support real-world scale identification

- “VIUTEK uDecore” application

  uDecore [14] is a customizable 3D room planner application which utilizes augmented reality technology for iOS devices. uDecore can support furniture models to be customized and placed in a virtual 3D room. A major benefit of the application is that it can work without active internet connection, as 3D furniture models can be permanently stored in the device after an initial setup.

- “Augment” mobile application

  Augment [15] make available a large collection of furniture with the help of markerless AR through a virtual furniture showroom allowing customers to try products at their desired location before purchase. Even though the application consists of advanced features like multiple object placement and furniture customization the lacking of marker-less which offer freedom for the user to view augmented objects from different locations.

3 METHODOLOGY

This research was conducted focusing on four major findings. They were;

1. Utilizing existing mobile markerless AR technologies and identifying their limitations.
2. Select the best option by comparing those technologies.
3. Implementation of a mobile application using the selected technology and achieving the prior mentioned specific features.
4. Overcome limitations which had arisen during the implementation of the application.

3.1 Methodology

The study was conducted with the use of both Wikitude and Kudan SDK separately to identify each SDK's limitation when utilized for implementing an AR furniture placement application. The development platform used for constructing the application was Unity 3D game development platform version 5.3.1 linked with the Visual Studio 2015 IDE for programming using C# language. Both Wikitude and Kudan offer SDKs for development through Unity platform and they both support development for Android or iOS mobile platform. For this study, the development was carried out for the Android mobile platform. The minimum Android version used was android 4.3 Jelly Bean (API level 18).

3.1.1 Wikitude AR and its limitation for AR furniture application

As discussed previously in the literature review, Wikitude uses a two-step mechanism for handling marker-less augmented reality. Let's analyze each step individually. First off is the mapping step.

To be able to use 3D tracking in a Wikitude powered application, you need to create something called a Tracking Map. This Tracking Map is a simple file (.wtm file) which contains all the information needed by the Wikitude SDK to track the 3D objects of your choice. The first step in Wikitude's 3D tracking is to create this Tracking Map. During the mapping of the real-world environment, the Tracking Map Record Class notify the user about the quality of the environment. This quality indication gives the user a first estimate of how well the tracking performance will be. There are three levels, which will be displayed.

- Bad: There are too few points available to recognize and track the object. Figure 3.1.1 (a).
- Average: There are few points available to recognize and track the object. This will result increased shaking and varying recognition results. Figure 3.1.1 (b).
- Good. The algorithm has found enough points to recognize and track the object. Figure 3.1.1 (c).

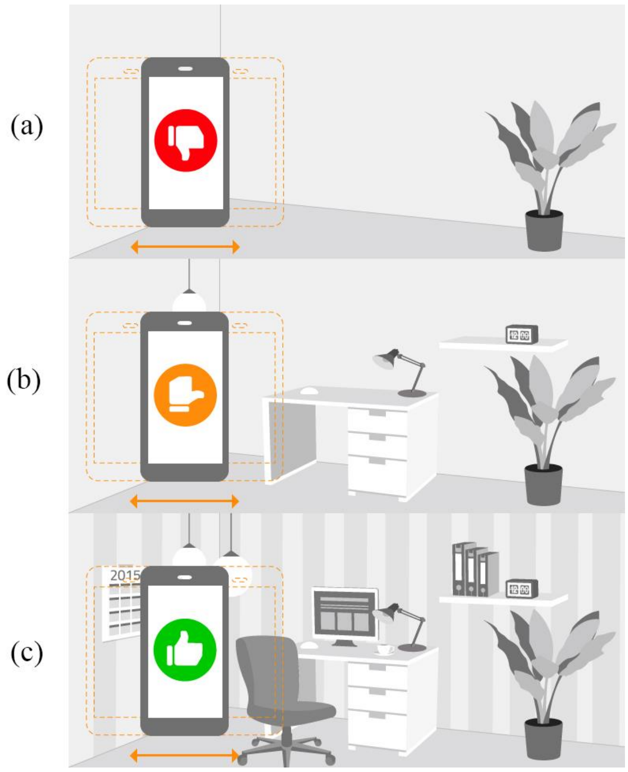

Figure 3.1.1 Wikitude's quality of the tracked environment
Source: https://www.wikitude.com/external/doc/documentation/5.2/iosnative/3dtracking-guidelines.html#3d-tracking-guidelines-and-best-practices

As seen from Figure 3.1.1, you can clearly identify that the level of quality that is determined by Wikitude's Map Recorder is directly proportional to how densely that environment is filled with items. Which in other terms means, more are the real-world objects more features will be detected and hence tracking quality will be high. Once a high-quality map has been recorded, the information will be then saved on Tracking Map (.wtm file).

Step two of Wikitude's 3D tracking concerns about augmenting the 3D objects onto the environment. This is done by obtaining information from the Tracking map file which was previously generated. The information obtain is use to compare with the real-world environment and at the moment when the information from both camera and the map file matches, the 3D object augmented to that real-world location. Next, as the augmentation is complete the users free to move around the real-world to view the augment 3D object from different angles provided that the camera can still identify the matched location. If by chance the detection is lost, the augmented 3D object will disappear from view. At this instant to augment the 3D object again, the user has to move back to the initial position where the system detected the match with the map information. Doing so the system will automatically detect and regenerate the augmentation with the same orientations as before the augmentation was lost.

The advantage of a Tracking map is this, as the mapped information is been stored for later use, the augmented details can be easily recovered once the tracking has been lost.

- **Limitations of Wikitude's 3D tracking**

The 3D tracking engine is currently optimized for small-sized scenes (table-size or scenes that stretch a few meters) and objects. Objects and scenes where the 3D tracking engine will not operate well

- Shiny object will minimal textures
- Tiny objects only measuring a few centimeters
- If illumination or lighting conditions changes
- Scenes containing few objects
- White (icy) walls.

3.1.2 Kudan AR and its Limitation for AR Furniture Application

As discussed previously in the literature review, Kudan AR used a single step mechanism for handle marker-less augmented reality. To achieve this Kudan used the mobile phone's camera feed. When a Kudan AR powered application is started, A Class called ‘KudanTracker’ will detect and obtain information about the mobile phone’s camera resolution and location of the default camera whether it is back or front facing. Then this information will be fed to the platform specific (Android/iOS) tracker class called TrackerBase which will initialize tracking. This class accesses the device’s native operations to identify the orientation of the camera feed and then convert the image feed obtained from the camera to match the application’s orientation and resolution. Once this is done the camera feed will be applied to a texture which is displayed to the user. Figure 3.1.2 depict the relationship between the prior mentioned classes.

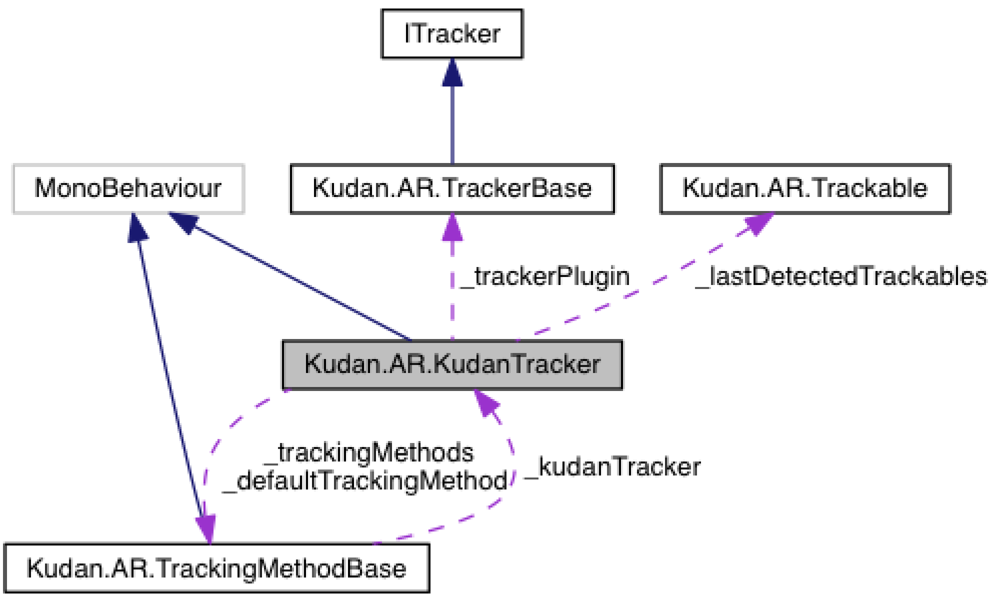

Figure 3.1.2 Kudan Tracker & TrackerBase Class diagram
Source: https://wiki.kudan.eu/apidocs/UnityDocs/class_kudan_1_1_a_r_1_1_kudan_tracker.html

The system will continue to perform this process till the user initialize marker-less tracking to augment a 3D object. When the user gives the command to activate marker-less placement of a certain 3D object, the system will call a method to retrieve the current orientation of the mobile phone. The information of this orientation is retrieved from the mobile phone's gyroscope. The information will be converted to identify the floor position and orientation as it is seen from the camera of the device. The system will then send this data to a method called 'ArbiTrackStart' (Short for the method which initializes Arbitrary tracking). Once this method is called the system will assign the orientation and floor position to a parent object which is tasked with holding the 3D object which is to be augmented. Once these locations has been set, the 3D object will be augmented onto the real-world.

The advantage of this procedure is that it helps to instantaneously initialize the augmentation of 3D objects without having to first scan the real-world to obtain a tracking map of the environment. This also means that the user can freely augment 3D objects onto the environment without having to be concerned about the quality of the tracking details in the environment or the size of the scene.

- **Limitations Kudan AR's Markerless Tracking**
    1. As no tracking map is produced, no information regarding the environment is stored, therefore if tracking is lost, the system will not automatically detect the initial augmented position.
    2. If initial environment tracking details are limited the augmented 3D object may seem to be a bit jittery.
    3. The system relies on a gyroscope of the device to obtain orientation.

3.1.3 Gyroscope and its Purpose in Mobile Phones

A gyroscope is a spinning wheel or disc in which the axis of rotation is free to assume any orientation by itself. When rotating, the orientation of this axis is unaffected by tilting or rotation of the mounting, according to the conservation of angular momentum. Because of this, gyroscopes are useful for measuring or maintaining orientation. [16]

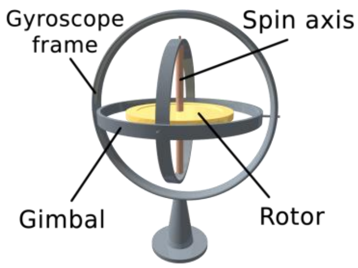

Figure 3.1.3 Gyroscope
Source: https://en.wikipedia.org/wiki/Gyroscope

The Accelerometer sensor in mobile phones are used to detect the orientation of the phone. In similar means to the regular gyroscope (Figure 3.1.3), the gyroscope sensor in mobile phones are used to detect the orientation of the phone. The gyroscope, or gyro for short, adds an additional dimension to the information supplied by the accelerometer by tracking rotation or twist.

An accelerometer measures linear acceleration of movement, while a gyro measures the angular momentum. Both sensors measure the rate of change. Figure 3.1.4 depict how accelerometer and gyroscope determine axis and orientations.

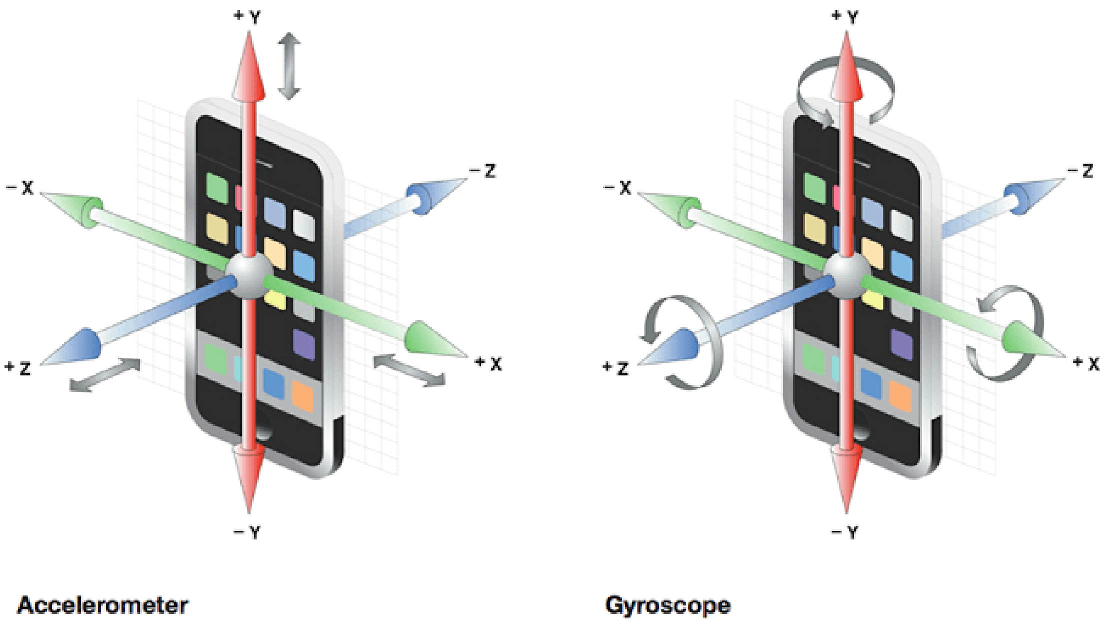

Figure 3.1.4 Axis identified by Accelerometer and Gyroscope
Source:
https://developer.apple.com/library/ios/documentation/UserExperience/Conceptual/DesigningExpandedAdUnits/FeaturesforExpandedAdUnits/FeaturesforExpandedAdUnits.html

3.1.4 Degree of Freedom

Kudan AR's Arbitrary tracking also allows 6 DoF. It refers to the freedom of movement in 3D space. The object is free to change position as forward/backward, up/down, left/right. [17]. This 6 DoF allow the user the freedom to move and freely observe the augmented object from a different position in the environment.

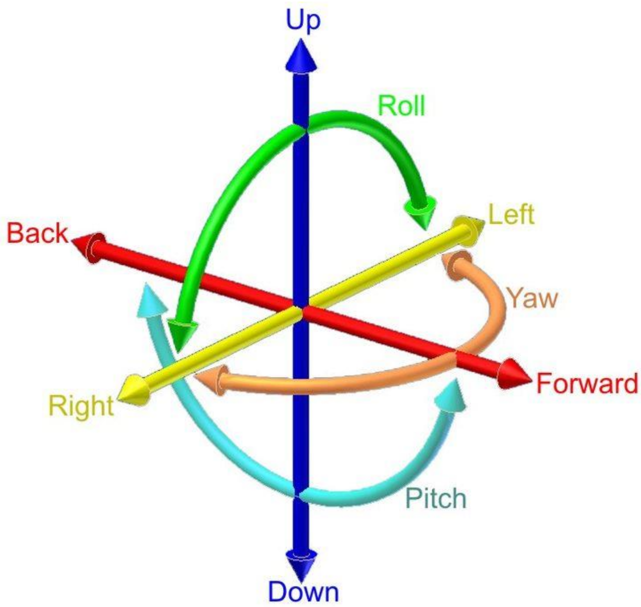

Figure 3.1.5 Six Degree of Freedom
Source : https://en.wikipedia.org/wiki/Six_degrees_of_freedom

3.1.5 Best Current Framework Option for AR furniture application

In Accordance with the details given in the previous section regarding both technologies for marker-less augmented reality, a comparison was done to identify the favorable features each one offers as well as the limitations that each of the methods imposes in regard to creating an augmented reality furniture placement application.

The comparison data was gathered by the operation of two sample applications which were created individually with the use of said technologies. The development was carried out for the Android mobile platform. The minimum Android version used was android 4.3 Jelly Bean (API level 18). The mobile phone use was an HTC one m9 which consisted of an Octa-core Processor (4x1.5GHz and 4x2.0GHz), 3GB of RAM and gyroscope.

Two real world locations were selected for augmenting furniture. First been and densely populated small room (Figure 3.1.6) and a partially fill a large room (Figure 3.1.7). The comparison was perform by answering a series of questions created for the experiment (Table 3.1.1).

Figure 3.1.6 Location 1: Densely populated room

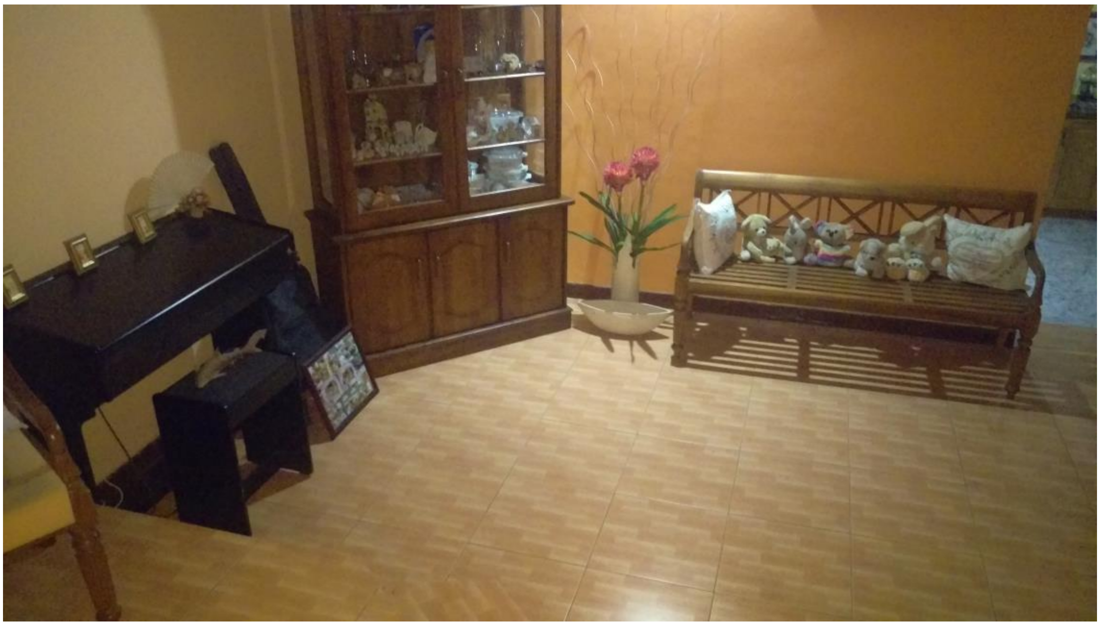

Figure 3.1.7 Location 2: Spacious room

- Difficulty was measured on a scale of 1 - 5, with 1 = easiest and 5 = hardest (This Difficulty defines the effort that should be taken to recognize the environment onto which the 3D object was augmented)
- Stability was measured in a scale of 0 - 5, with 1 = unstable and 5 = most stable (This stability defines stability of the augmented 3D object when user moves around the environment)

Table 3.1.1 Sample Application Comparison

	Wikitude Application	Kudan AR Application
The time is taken for application to start up	5.2 sec	4.3 sec
Difficulty to augment a 3D object onto location 1	3	1
Difficulty to augment a 3D object onto location 2	4	1
Stability of augmented 3D object in location 1	3	4
Stability of augmented 3D object in location 2	2	3
Does system identify the location again if tracking is lost?	Yes	No
Tracking re-initialization auto/manual	Auto	Manual
The amount of RAM usage for application	503 KB	300 KB

From the Table 3.1.1 comparison, we can conclude that the best and efficient framework to use when creation a marker-less is Kudan AR. Not only did Kudan framework easily augment the 3D objects onto the two different locations given but the stability of that augmented item was also higher than the Wikitude's application. But one drawback remains which is if tracking is lost, the user needs to manual re-initialize it in Kudan AR application.

3.2 Testing and Implementation

3.2.1 Implementation of "Markless Furniture" application

The "Markless Furniture" application consist of four main components as shown in table 3.2.1

Table 3.2.1 System Components

Component	Component Name	Sub Components
1.	Augmented reality furniture placement.	i. Implement marker-less augmented reality features. ii. Furniture customization. iii. Multiple furniture handling. iv. Changing orientation of augmented Furniture
2.	Furniture suggestions	i. Suggestion feature for mobile application with filter search. ii. Enhance image details. iii. Identify prominent colors. iv. Generate suggestions. v. Development of Web API to access services. vi. Develop database manager application to efficiently insert data records during development.
3.	Voice recognition.	i. Text to voice feature. ii. Customize furniture according to voice commands.
4.	Scale identification.	i. Identify real world scale to determine the actual scale of furniture.

The system uses a cloud-hosted web API in order to facilitate the mobile application with implemented services and data access protocols through the active network (internet) connection, while the API internally connects to a hosted SQL database to retrieve and manipulate persistence data. The high-level system diagram (figure 3.2.1) shows the interrelation between the internal components of the mobile application.

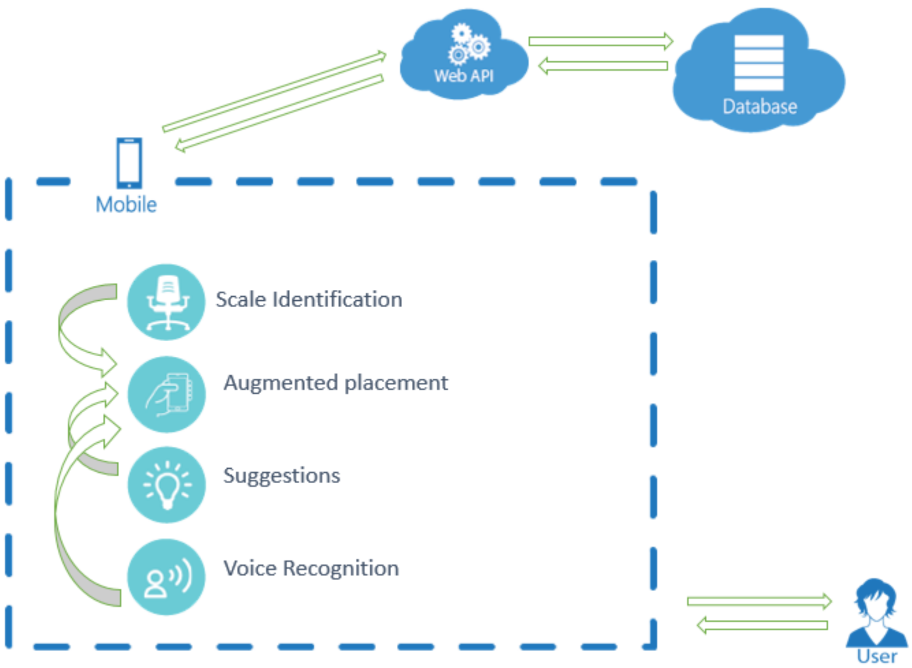

Figure 3.2.1 System diagram of the Application

This sub-topic will explain the high-level structure of implemented application and the features offered for the user through the augmented placement component and the process through which they operate.

- **User interfaces**

The "Mark-less Furniture" mobile application has main four features as seen from figure 3.2.1 are represent in a separate interface, out of which the "Augmented Furniture Placement" Component act as the main interface. Figures 3.2.2 – 3.2.5 represent the user interface while a 3D object is augmented.

Figure 3.2.2 Main User interface with augmented Furniture

Figure 3.2.3 Main user-interface with Furniture download Feature

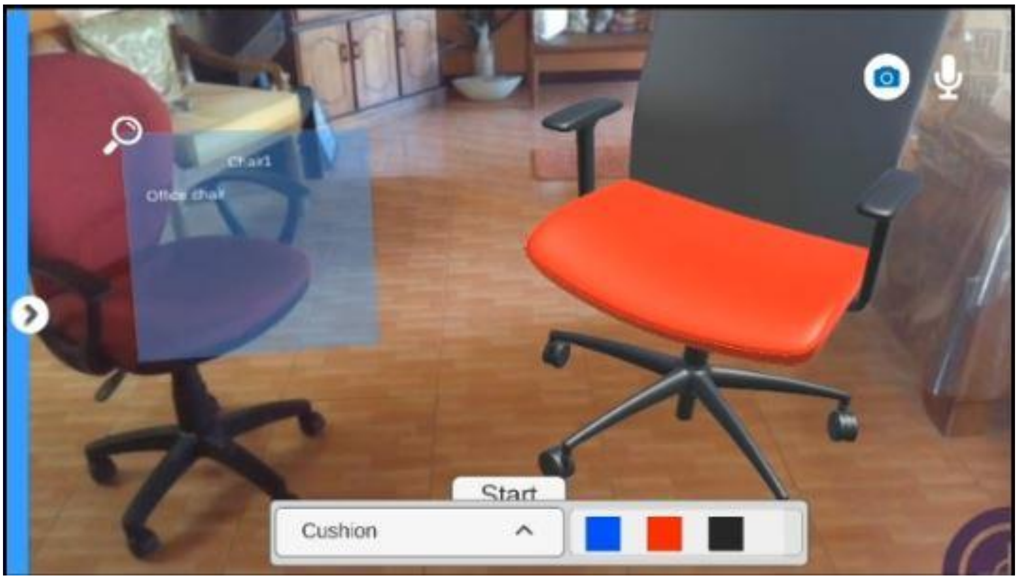

Figure 3.2.4 Main user-interface color customization feature

Figure 3.2.5 Main user-interface texture customization feature

The class diagram in Figure 3.2.6 represents the integration between the application logic with the Kudan AR framework implementation. The application logic is concerned with handling the operation of download, augmentation, and customization for 3D models of furniture.

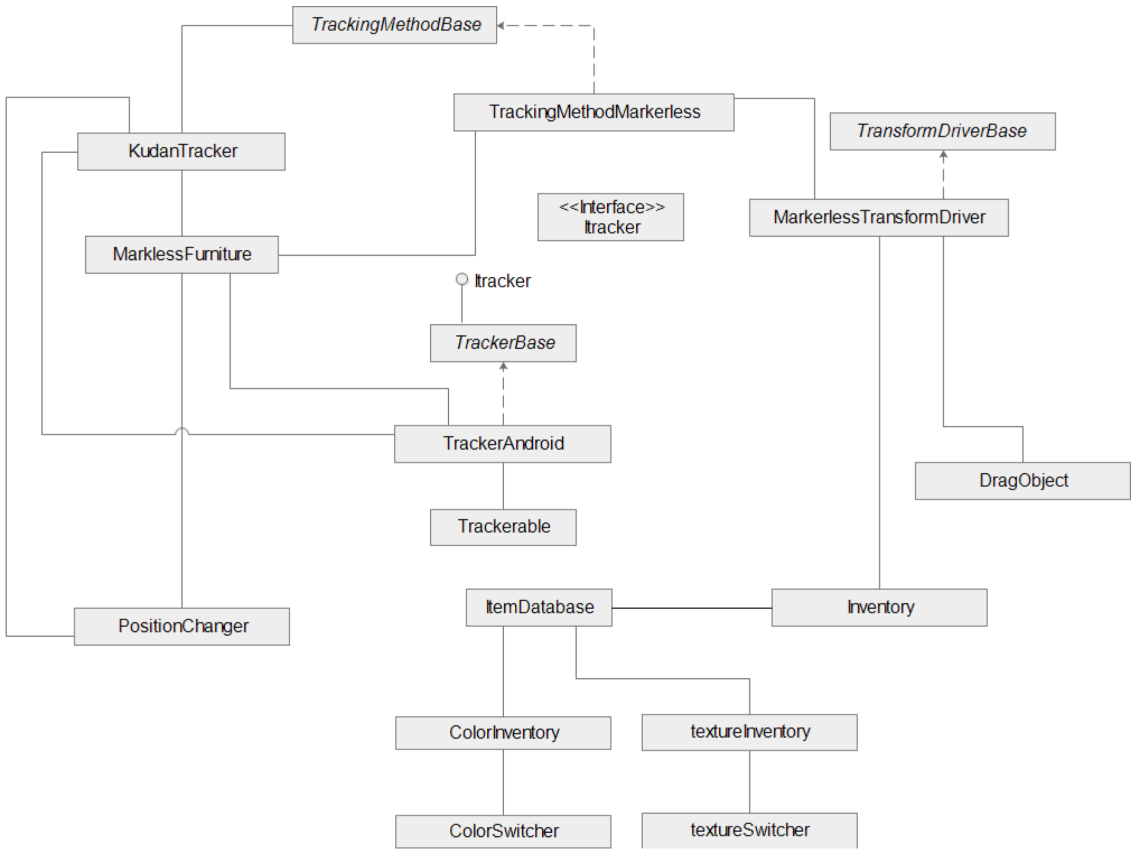

Figure 3.2.6 Kudan Framework and application logic integration

With reference to Figure 3.2.6, the definition of each class is given below

- **ITracker**

This holds all abstract methods necessary for obtaining the identification and initialization of the camera

- **TrackerBase**

This is an abstract class which holds all the implementations of the ITracker interface, with several abstract methods for initializing the arbitrary tracking feature of Kudan AR, utilizing the gyroscope of device and projecting camera feed onto a texture

- **TrackerAndroid**

This class extends the TrackerBase class and override the methods to provide Android platform specific functionality of abstract method given in TrackerBase. This class holds the implementation which obtains the camera feed and converts the images into a texture which can be applied on a plane surface where the user can see. As a camera feed is a continuous flow of a sequence of images (frames) per second, this method is continuously executed in order to update the texture.

This class is also tasked with identifying the orientation of the floor through the use of gyroscope sensor information.

- **KudanTracker**

This Class holds all the functionality necessary for identifying the method of Tracking (whether it is marker-based AR or markerless AR) and to start the device camera, obtain texture of camera feed retrieved by TrackerAndroid class and applying it to the plane surface which will be seen by the user.

KudanTracker is also tasked with identifying the status of the tracking once the 3D objects are augmented onto the environment.

- **Trackerable**

This class holds the information of the current position, the orientation of the augmented object as well as whether the augmented Object is been tracked or tracking is lost.

- **TrackingMethodBase**

This is an abstract class which contains the information and abstract methods for identifying the tracking methods, whether it is marker-less or marker-based.

- **TrackingMethodMarkerless**

This class extends the TrackingMethodBase class and provide the implementation of identifying the tracking method which is been used as “Markerless AR”.

This class also contains a method to process current frame and identify whether the system is still in tracking state or whether the tracking is lost, as well as identifying the position of the augmented objects in the real-world. This information is fed to the Trackerable class, which in-turn be utilized to manipulate the augmented objects.

- **TransformDriverBase**

This abstract class holds the methods necessary for registering or unregistering the augmented object visibility when the tracking status is true or false.

- **MarkerlessTransformDriver**

These methods hold the implementation of methods declared in TransformDriverBase with respect Markerless AR. The 3D Objects that are to be augmented are assigned to a parent Unity GameObject which will utilize the MarkerlessTransformDriver class to manipulate the visibility, position, and orientation of them.

- **PositionChanger**

This class contains methods to continuously record the distance between the mobile phone’s camera and the augmented object as well as the direction. It also records the cardinal directions to which the camera was held when the tracking was initialized or when the tracking was lost.

This information will then be used when the tracking is lost in order to restart the tracking automatically when the re-enters the same cardinal direction.

- **Itemdatabase**

This class is a task with downloading the specific 3D object that the user wishes to augment and sorting out the information of that downloaded item into item information, the 3D object, the 3D object’s color customization information as well as its texture customization information.

- **Inventory**

The Inventory class contains methods to send information to Itemdatabase regarding the item to be downloaded, and methods to Add or delete the downloaded item. This class is also concerned with inputting the 3D object which was downloaded on the Parent Unity gameObject which contains the MarkerlessTransformDriver class in order for that 3D Object to be augmented onto the real environment.

- **Color Inventory and Texture Inventory**

These two classes handle the color or Texture (example for texture if regard to 3D models of furniture are the images of material by which the furniture are been made, Teak or mahogany) information of the downloaded furniture items.

- **Color Switcher and Texture Switcher**

Once the 3D model of the furniture is been downloaded, its respective color and texture information are downloaded and once the model is been augmented, These two class are tasked with identifying selected augmented 3D model and display the color/texture options it contains in order for the user to customize the furniture.

- **DragObject**

This class is tasked with changing the position or the orientation of each 3D object which is been augmented. The user are allowed to select whether he/she wish to change the position or orientation and once it is been selected the user can select one augmented 3D object and change the position or the orientation.

3.2.2 Features Offered through Augmented placement Component

1. Augmentation of 3D furniture through marker-less augmented reality means onto the environment.
2. Obtain the real-world scale of the environment prior to the augmentation and utilize that value to augment item to the actual scale.
3. Allow to change the position and vertical rotation of the object and augment several items at once onto the scene.
4. Represent the furniture dealer's description of the furniture on an augmented panel next to the 3D furniture.
5. Allow to customize the 3D furniture's color or texture as per the specifications are given by the dealer.
6. Allow a means to narrate the description as well as customize furniture through voice recognition.

The operation of each of these features are carried out in the follow manner as depicted in figure 3.2.7. Out of these features, the previously mentioned features 1, 3, 4 operated on top of the augmented reality functionality of the Kudan framework.

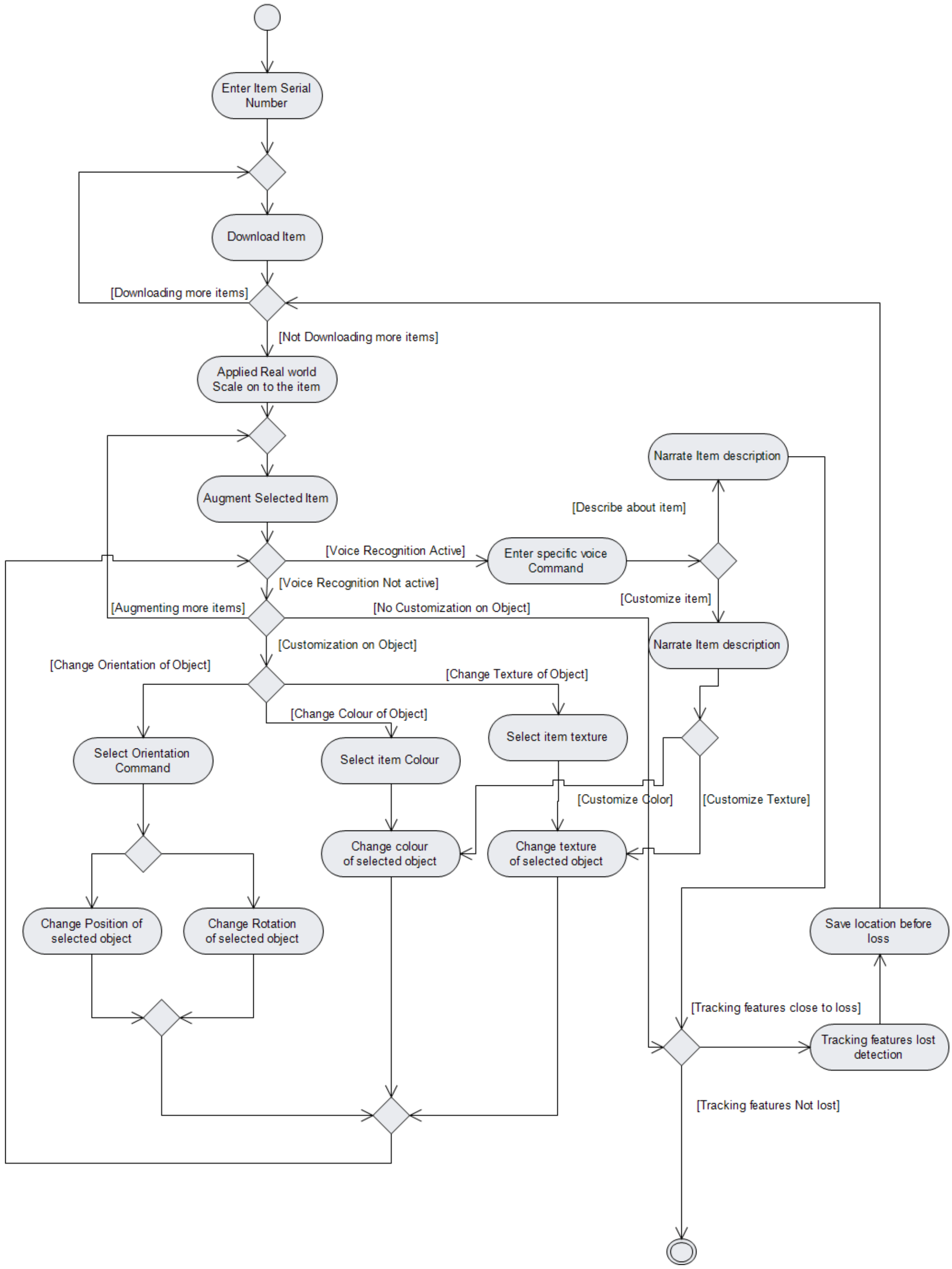

Figure 3.2.7 Activity diagram of process

3.2.3 Testing

The “Markless Furniture” application was unit tested through the course of implementation in order to ensure that each module functioned according to the expected output, and tested during the integration of each module to ensure that the system was error free with each iteration of integration. After all integration testing were complete the overall system was tested to ensure that the final product is free of error and usable by the end user. User acceptance testing was done by two users in the furniture industry. Since performance is a high priority concern in a networked application, the “Markless Furniture” application was thoroughly tested for performance issues.

Performance Requirement

i. The mobile application should download details and 3D model of furniture and augment them to the desired real world location under 1 minute.
ii. The system operates correctly customize selected 3D model of furniture with the given customization option instantly with any delay.

Assumptions

i. Memory

   The mobile device memory should be 512 MB or above to run the application on normal conditions.

ii. Network Connection

   The network should possess download bandwidth at least of 7.2Mbits/seconds and upload bandwidth at least of 3.6Mbits/second for smooth performance.

iii. Operating System Version

   The mobile phone’s operating system should be of android operating system, version 4.3 (Jelly Bean) or newer.

3.3 Research Findings

In the current context, Furniture marketing is difficult as customers who purchase furniture may ask for refunds on the product due to dissatisfaction either with the design of the product itself when it was placed in the location that he/she wished, or due to their personal liking changing over time. “Markless Furniture” application was designed in order to overcome this difficulty. The use of this application by customers will help to improve the above-mentioned issue, as well as increase the customer user interaction. It will also increase the profit of dealer as the customer satisfaction is increased while decreasing the risk and burden involving transport of furniture.

The future work for the application include further improvement of the look and feel of the mobile application, improving the immersiveness of the Augment Reality with the introduction and integration with Virtual Reality, improving to identify real-world lighting conditions and applying them to the augmented object.

4 RESULTS AND DISCUSSION

4.1 Results

“Markless Furniture” is an application for improving the issue furniture marketing, and to ease the difficulties faced by both customers and dealer. The system was a success as it has received numerous positive feedbacks from both parties.

The product has been proven to operate in a wide range of mobile phones which operates on android 4.3 or newer. The application has been tested for operation under different internet connections and performance capabilities.

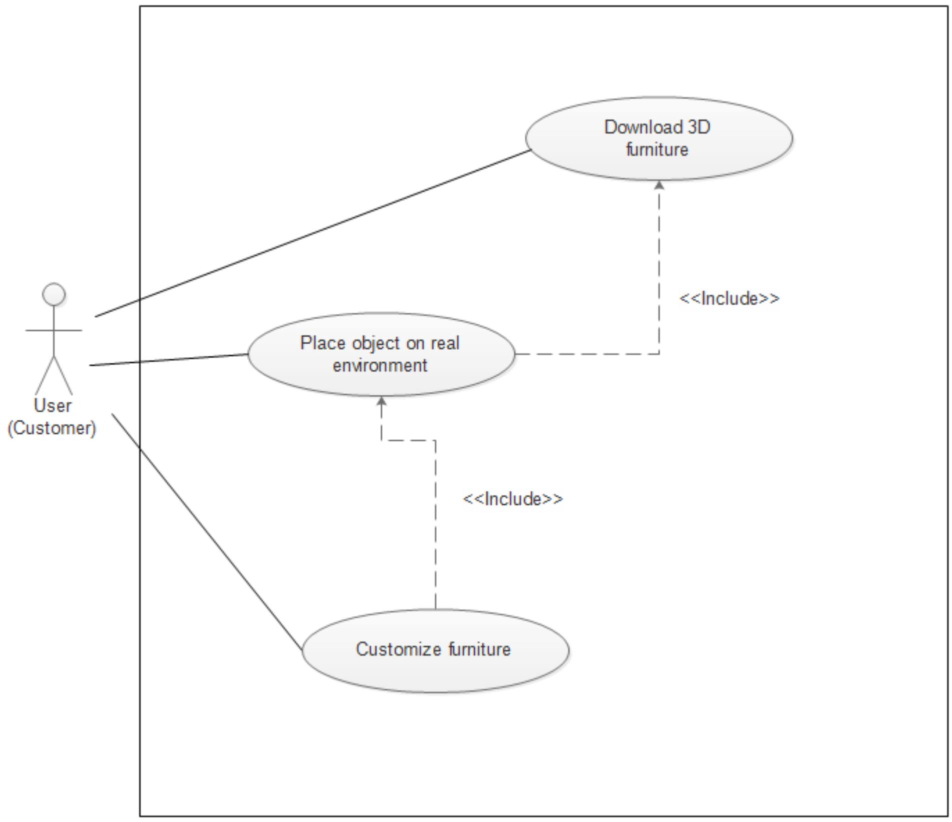

Figure 4.1.1 Use-case Diagram

Follow are the test cases with reference to use-case diagram Figure 4.1.1

4.1.1 Testing

- Download furniture

Table 4.1.1 Test Case 01

Test Case ID	01
Description	Download 3D furniture successful
Pre-conditions	• Device is connected to the internet • Application is open
Steps	1. Open the left panel by clicking the arrow sign button on the left of the window 2. Click on the top “plus” sign button 3. Enter the serial number 4. click the download button
Inputs	Serial No : itm001
Expected Output	3D furniture image appears in one of the slots
Actual Output	3D furniture image appears in one of the slots

Table 4.1.2 Test Case 02

Test Case ID	02
Description	Download 3D furniture unsuccessful
Pre-conditions	• Device is connected to the internet • Application is open
Steps	1. Open the left panel by clicking the arrow sign button on the left of the window 2. Click on the top “plus” sign button 3. Enter the serial number 4. click the download button
Inputs	Serial No : itm1
Expected Output	the message box is displayed with “Serial number invalid message” message
Actual Output	the message box is displayed with “Serial number invalid message” message

- Furniture Library component

Table 4.1.3 Test Case 03

Test Case ID	03
Description	Selection of furniture for placement
Pre-conditions	• One slot is filled with an item
Steps	1. Open the left panel by clicking the arrow sign button on the left of the window 2. Click on slot with item
Inputs	
Expected Output	the message box is displayed with “Item ready to augment” message
Actual Output	the message box is displayed with “Item ready to augment” message

- Customization component

Table 4.1.4 Test Case 04

Test Case ID	04
Description	Change of Colour of furniture
Pre-conditions	• One item is augmented onto the environment • The item has color customization options
Steps	1. Switch to color customization by sliding the bottom right corner button to down once 2. Click on the button 3. click on the red color button
Inputs	
Expected Output	The augmented item’s color changes to red
Actual Output	The augmented item’s color changes to red

Table 4.1.5 Test Case 05

Test Case ID	05
Description	Change of texture of furniture

Pre-conditions	• One item is augmented onto the environment • The item has texture customization options
Steps	1. Switch to texture customization by sliding the bottom right corner button to down twice 2. Click on the button 3. click on the 1st texture button
Inputs	
Expected Output	The augmented item’s texture changes to teak
Actual Output	The augmented item’s texture changes to teak

4.1.2 Performance Testing

Several performance tests were also carried out to identify the connections speed and load of the device. These tests were defined as follows.

- **Furniture download speeds testing**

The Implemented Mobile application was tested under Edge, HSPA+, LTE mobile network connection categories. The mobile phone used for testing was HTC one m9. The test was carried out to download three different furniture models with different size (storage sizes). Each individual model consisted of general product information (name, description, height, width, length, and company details), the 3D object, color customization options, and texture customization options. Refer Table 4.1.6.

Table 4.1.6 Performance Test for downloading Items

3D Model Name	**Size (KB)**	**Time taken to download the Model (seconds)**		
		Edge (384Kbps)	**HSPA+ (7.2Mbps)**	**LTE (41Mbps)**
Chair1	586 KB	15.4s	9.5s	2.3s
Bed	1740 KB	22.7s	14.8s	4.6s
Table	2640 KB	27.2s	18.2s	8.2s

- **Number of Augmented furniture with CPU usage**

The test was performed with the same mobile phone running on normal and power saving performances, and augmenting 20 instances of "Chair1" 3D model (refer Table 4.1.6 for the size of 3D model) onto the environment. Refer Table 4.1.7.

Table 4.1.7 CPU usage testing

Normal/Power saving Performance	**Number of Active Cores**	**Core speeds**	**CPU usage (%)**
Normal	8 cores	4x1.5GHz, 4x2.0GHz	13.99 %
Power saving	4 cores	4x1.5GHz	19.59%

Next test was carried out to identify the CPU usage and RAM usage when the number of augmented furnitures are increased (Table 4.1.8)

Table 4.1.8 Number of furniture to CPU and RAM using

Number of Augmented Furniture	**CPU usage (%)**	**RAM usage (MB)**
1	10.06	7
5	11.72	10
10	12.5	14
20	13.99	19
50	20.85	31

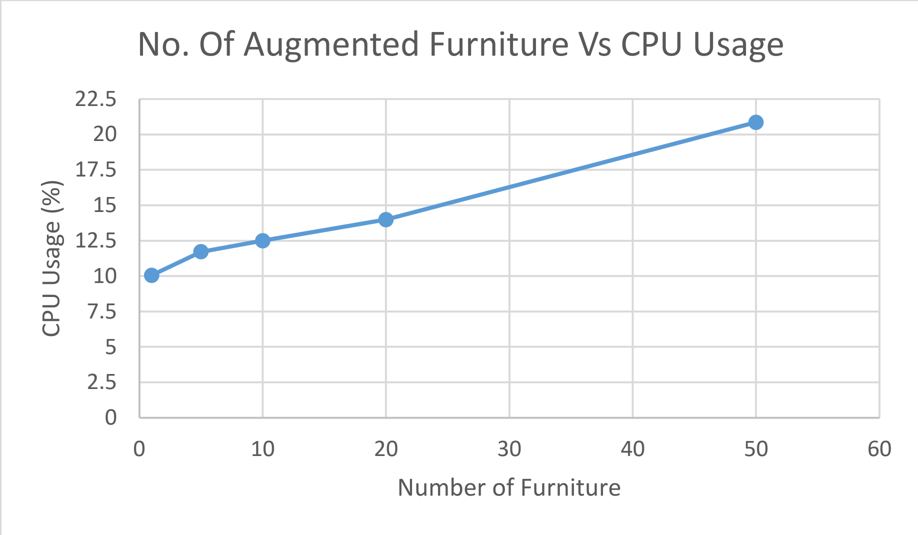

Figure 4.1.2 Number of Augmented Furniture against CPU Usage

4.2 Discussion

This portion mainly focuses on discussing the problems faced during design and implementation and how those issues were resolved. This section also describes how the successful achievements are gained.

The research project “Markerless Augmented Reality Interactive Furniture Layouting” was started in January 2016, to find a solution for a pending problem faced by customers in the furniture market. The solution was identified as creating a mobile application with the utilization of an emerging field in Augmented Reality called “Markerless AR” to download and place 3D models of furniture that a customer wish to purchase. The next step that arose was to carry out and identify what kind of technology can be used for the implementation. A literature survey was carried out to identify whether similar types of products were available and if so what limitation were there, and an analysis was carried out to identify and test existing technologies for achieving Markerless augmented reality in mobile phones. Through this analysis, the best technology was obtained on top of which the implementation of the product was started. During the course of the implementation, the application logic was integrated with the framework offered by the previously selected technology to give the user of the application a product which is both easy to operate as well as accurately perform the functionality. During this implementation, an issue was identified which limited the functionality of augmenting reality due to the selected technology relying on a mobile phone's gyroscope to give the correct orientation after the 3D object is been augmented. The application could still operate on a mobile phone which does not have a gyroscope but had a problem of augmented 3D objects always facing toward the camera no matter which direction from which the object was viewed. The issue was resolved by allowing the user to correct the orientation when he changes the viewing position.

After the implementation was completed the application was tested through a series of test cases of operation and performance. From the test information gathered during the testing process, it is clear that the time was taken to download the furniture information depend highly on the network connection quality. Also through the CPU usage testing, it was confirmed that the amount of application load on CPU is minimum.

The end product was then given to several users to operate and provide feedback.

5 CONCLUSION

Designing and marketing of furniture according to the exact requirements of the customer has always been a pending problem in the furniture industry. Customers who purchase furniture from dealers had to wait till the furniture arrives at the location in order to check if that product matches with the expectation they had when purchasing it. Customers get dissatisfy with the purchased product due to the colors, design or scale not suiting the location where they wanted it to be placed. Therefore this research was carried out in order to find solutions to improve this mentioned problem.

This research study provided a solution by developing a system “Markless Furniture” with the use of a newly emerging technology called Markerless Augmented Reality. This system mainly focused on developing a mobile application that helps to augmented 3D models of Furniture onto any environment without having to rely on pre-defined markers, and giving the mobility for the user to view the product from different locations after the model is been augmented, as well as giving the freedom for the user to customize the appearance of the product according to the specifications given by the dealer. The system recognized the real world scale and utilize the information to give the real scale onto the augmented model so that they might also appear in actual scale to the real product. All these functionality together were used to meet the ultimate goal of this research which is to overcome the difficulties customers face when purchasing furniture to suit their expectations.

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