

**DOKUZ EYLÜL UNIVERSITY**  
**GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES**

**COMPUTER-SUPPORTED DESIGN AND  
COMPUTER-SUPPORTED MANUFACTURING  
(CAD/CAM) APPLICATION IN  
PROJECTOR-SUPPORTED  
CUTTING AND PLANNING PROCESS**

**by**  
**Ali YILDIZ**

**January, 2015**  
**İZMİR**

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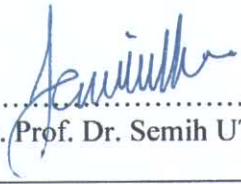
**A Thesis Submitted to the  
Graduate School of Natural and Applied Sciences of Dokuz Eylül University  
In Partial Fulfillment of the Requirements for the Degree of Master of Science  
in Computer Engineering, Computer Engineering Program**

**by  
Ali YILDIZ**


**January, 2015  
İZMİR**

## M.Sc THESIS EXAMINATION RESULT FORM


We have read the thesis entitled “**COMPUTER-SUPPORTED DESIGN AND COMPUTER-SUPPORTED MANUFACTURING (CAD/CAM) APPLICATION IN PROJECTOR-SUPPORTED CUTTING AND PLANNING PROCESS**” completed by **ALİ YILDIZ** under supervision of **ASST. PROF. DR. SEMİH UTKU** and we certify that in our opinion it is fully adequate, in scope and in quality, as a thesis for the degree of Master of Science.

  
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I would like to dedicate this work to my wife Ayg l YILDIZ for her support and patience during the development and writing of the thesis.

Ali YILDIZ

# **COMPUTER-SUPPORTED DESIGN AND COMPUTER-SUPPORTED MANUFACTURING (CAD/CAM) APPLICATION IN PROJECTOR- SUPPORTED CUTTING AND PLANNING PROCESS**

## **ABSTRACT**

Projector supported cutting and planning machines also known as CNC machines are industrial devices which automatically perform mechanical process to be executed according to commands from a computer mounted on them. For faster, efficient and accurate working of modern CNC machines, computer-aided design (CAD) and computer-aided manufacturing (CAM) applications are used.

In traditional method of leather cutting, wooden or cardboard patterns prepared for the model to be manufactured and a knife are used. Cutting process is performed by using patterns as a guide and a knife. Furthermore, in modern CNC machines, cutting process completes with steps those; designing patterns with using CAD/CAM applications and then manufacturing operation.

The thesis is aimed at designing the solution that includes converting patterns that are used in traditional methods to the CAD/CAM application which will be used in projector supported cutting and planning process, allowing the necessary actions in designing and programming the cutting machine according to the design.

To give a solution, a CAD/CAM application that it is called as GCAD, can import scanned pattern image and convert to a vector image was implemented. It also converts the design to G-Code and ILDA standards for CNC machines.

**Keywords:** Computer-aided design, computer-aided manufacturing, CAD, CAM, image processing, edge detector

# **PROJEKSİYON DESTEKLİ KESİM VE PLANLAMA SÜRECİNDE KULLANILACAK BİLGİSAYAR DESTEKLİ DİZAYN VE BİLGİSAYAR DESTEKLİ İMALAT (CAD/CAM) UYGULAMASI**

## **ÖZ**

Projeksiyon destekli kesim ve planlama makineleri bir başka deyişle CNC makineleri, üzerindeki bir bilgisayardan gelen komutlara göre yapılması gereken mekanik işlemi otomatik olarak gerçekleştiren endüstriyel cihazlardır. Modern CNC makinelerinin daha hızlı, verimli ve hatasız çalışabilmesi için bilgisayar destekli dizayn (CAD) ve bilgisayar destekli imalat (CAM) uygulamaları kullanılmaktadır.

Deri kesme işleminin geleneksel yönteminde, yapılacak olan modele uygun karton ya da tahta şablonlar ve bir bıçak kullanılır. Kesim işlemi şablonlar kılavuz olarak kullanarak bıçak yardımıyla yapılır. Modern CNC makinelerinde ise kesim işlemi, şablonların CAD / CAM uygulamaları kullanılarak tasarlanıp imalat işlemine geçilmesiyle olur.

Bu tez, geleneksel yöntemlerde kullanılan şablonların, projeksiyon destekli kesim ve planlama sürecinde kullanılacak olan CAD/CAM uygulamasına aktarılması, tasarımda gerekli işlemlerin yapılmasına olanak sağlamak ve kesim makinesini tasarımlara göre programlayabilmeyi kapsayan çözümün tasarımı hedeflemektedir.

Çözüm vermek adına, GCAD olarak isimlendirilen ve geleneksel şablonların taranmış resimlerini içeriye aktarabilen ve bir vektör resme dönüştürebilen bir CAD/CAM uygulaması geliştirildi. Bu uygulama aynı zamanda bu tasarımı CNC makineleri için G-Kod ve ILDA standartlarına dönüştürebilmektedir.

**Anahtar kelimeler:** Bilgisayar destekli dizayn, bilgisayar destekli imalat, CAD, CAM, görüntü işleme, kenar bulma

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## **CHAPTER ONE**

### **INTRODUCTION**

It is not profitable or efficient to produce everyday products with hand and traditional methods in industry. It can be produced by thousands of same item in a day on a CNC machine.

CNC machines are industrial devices which automatically perform mechanical process; but it is just a machine. If they are not supported by appropriate CAD/CAM application, they cannot give the most benefit and profit that is expected. For the most benefit, CAD/CAM applications must take traditional methods as well as input, too. Applications should facilitate the design process. Users of CAD/CAM application that is old hand-made designers shouldn't redesign all design because of new techniques.



Figure 1.1 A sculpture manufactured by a CNC machine

Manufacturing of the sculpture in above figure takes a long time – it probably takes a couple of weeks. It takes just minutes and can be made mass production with a CNC machine that is supported by an appropriate CAD/CAM application.

## 1.1 Overview

Projector-supported cutting machine is a type of CNC machine that is used in industry. Thus CNC machine must be explained before the cutting machine. CNC means Computer Numerical Control. This means that a computer converts the design produced by Computer Aided Design application (CAD), into numbers. The numbers can be considered to be the coordinates of a graph and they control the movement of the cutter. In this way the computer controls the cutting and shaping of the material.

There are a lot of types of CNC machines, but some of major categories of CNC can be covered like that.

- CNC Milling Machines
- CNC Machine Lathes
- CNC Routers

Milling is the machining process of using rotary cutters to remove material (Brown & Sharpe 1914, p. 7.) from a work piece advancing or feeding in a direction at an angle with the axis of the tool (CMMC 1922, p. 122., Usher 1896, p. 142.).

Lathe is a machine tool which rotates the work piece on its axis to perform various operations such as cutting, sanding, knurling, drilling, or deformation, facing, turning, with tools that are applied to the work piece to create an object which has symmetry about an axis of rotation (“Lathe”, n.d.).

A CNC router is one of many kinds of CNC machines. It is a computer supported machine for cutting various hard materials, such as wood, composites, aluminum, steel, plastic, foams and leathers. A CNC router is actually a type of CNC milling machine (“CNC router”, n.d.).



Figure 1.2 CNC Leather Cutter that a kind of CNC Router

However they have a common property. It is working on axis. 2D manufacturing has 2 axis and 3D has 3 axis. The X, Y and Z axis control the movement of the cutter on a 3D CNC machine. This allows materials to be machined in three directions. It is also known as 3D manufacturing.

A CNC machine should be supported by an appropriate CAD/CAM application. So CAD and CAM must be defined.

Autodesk (2014) defines CAD like that “CAD, or computer-aided design and drafting (CADD), is the use of computer technology for design and design documentation. CAD software replaces manual drafting with an automated process.” So CAD application uses a computer technology that designs a product and increases the productivity of the designer. It improves quality of documentation.

Computer-aided manufacturing (CAM) is defined simply as programmable automation which is used primarily on the factory floor to help produce products (Automation, C. M. 1984, p. 48.). CAM application uses computer and machinery to automate manufacturing. It usually converts CAD design and other operations to G-Code that run on CNC machine.

## **1.2 The Goal of the Thesis**

CNC machines are industrial machines that run automatically mechanical process to be executed with commands from a computer. CAD/CAM applications are used for faster, efficient and accurate working of CNC machines.

In traditional method of leather cutting, wooden or cardboard patterns prepared for the model to be manufactured and a knife are used. Cutting process is done with using patterns as a guide and a knife. Furthermore, in modern CNC machines, cutting process completes with steps those; designing patterns with using CAD/CAM applications and then manufacturing operation.

Given that CAD software replaces manual drafting with an automated process. So CAD software must not skip the replacement in its support and it must import manual drafts.

The goal of the thesis is implementing an application that can import manual patterns as scanned image. By this way, the application can convert the image to a design as vector image, and can convert the design to machine programs with G-Code and ILDA standards of projection supported CNC.

## **1.3 Thesis Organization**

This thesis is divided into 5 chapters. The description of basic terms like CAD, CAM and CNC machines and the goal of the thesis is given in Chapter 1. In Chapter 2, related works are given about CAD/CAM applications. Chapter 3 explains the methods of the solution in this thesis. Chapter 4 focuses the CAD/CAM application that gives a solution to the goal of thesis. In Chapter 5 there is the conclusion.

## CHAPTER TWO

### RELATED WORKS

There are commercial and open source solutions for CAD/CAM operations. In this section, Caligola by Comelz s.p.a, ElitronCAD 2D Footwear by Elitron, FootwearCAD by MiriSys Software S.r.o, AutoNester-L by Fraunhofer SCAI, BobCAD-CAM for Router, WaterJet & Plasma by BobCAD-CAM Inc., Delcam CRISPIN PatternCut by Autodesk, FreeCAD by Havre & etal., and LibreCAD by LibreCAD community will be investigated and compared with our evaluation and measurement tool.

Table 2.1 Comparison of CAD/CAM applications

	OS			Licence	Type	Depende ncy	Importing Manual Patterns
	Win	Mac OSX	Linux				
Caligola	✓	✓	✓	Proprietary	CAD / CAM	Comelz CNC Machines	✓
ElitronCAD	✓	✗	✗	Proprietary	CAD	✗	✓
FootwearCAD	✓	✗	✗	Proprietary	CAD	✗	✓
AutoNester-L	✓	✗	✗	Proprietary	Nesting Tool	✗	
BobCAD- CAM	✓	✗	✗	Proprietary	CAD / CAM	✗	✗
PatternCut	✓	✗	✗	Proprietary	Nesting Tool	✗	
FreeCAD	✓	✓	✓	LGPL	CAD	✗	✗
LibreCAD	✓	✓	✓	GPLv2	CAD	✗	✗

#### 2.1 Caligola by Comelz s.p.a

Caligola software solution is one of the commercial products. It was developed by Comelz s.p.a in Italy. It works on Microsoft Windows, Mac OS X and Linux platforms. This cad software is developed for leather industry. It can be used only with CAM applications that are developed by Comelz machines.

It reinforces to design shoe patterns. It can be open to every CAD/CAM systems to import, export and edit patterns in DXF format. It is interactive with Comelz to send patterns, comments and automatic error reports to the Comelz support server, directly from Caligola (“*Caligola 4*”, n.d.).

Caligola has different ways of acquiring lines and patterns. It can acquire manual shoe patterns by scanner, digitizer, background image etc. It has six steps to acquire by scanner

1. Scan the pieces
2. Detect boundary from image
3. Change some internal part as stencils or holes
4. Create pieces by the automatic external boundary mode
5. Give a name, set the material and the quantity
6. Ready for next

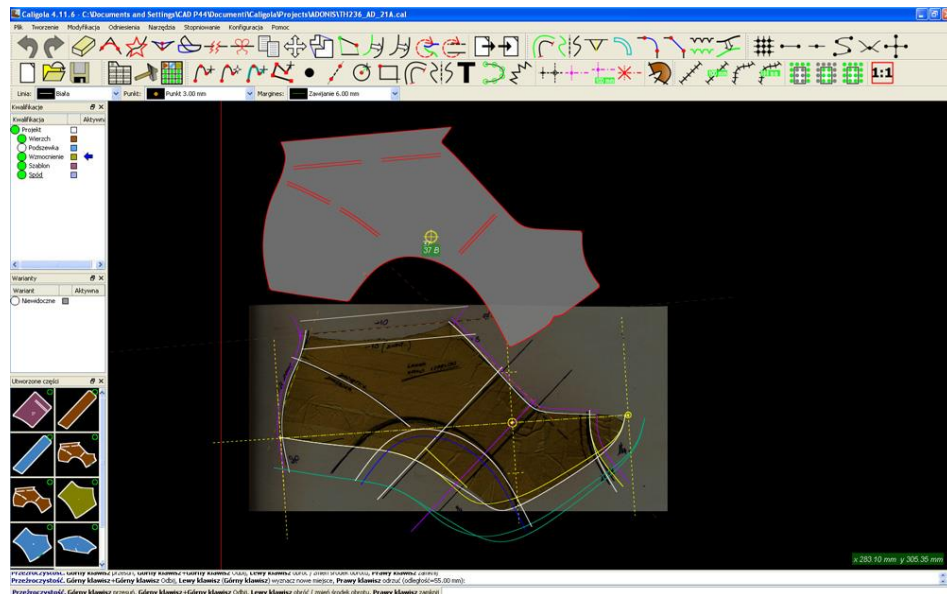


Figure 2.1 Designing with a background image

Caligola has leather goods, shoes and bottom templates for designing process. It has a grading area to give different grading rules to some areas of the model which is useful for the leg of the boots and other part of the shoes that have different grade increments and rules. It can generate automatically all shoe sizes from a size for shoe bottom.

## 2.2 ElitronCAD 2D Footwear by Elitron

Another commercial product is ElitronCAD 2D Footwear. It works on Microsoft Windows platform. It is a CAD design system that was developed by Elitron. It can be used with another CAM system. It is created for designing in footwear industry. Elitron has also similar software that is known as ElitronCAD 2D Leather Goods. It is a CAD-CAM system specifically for leather. It has similar characteristic with ElitronCAD 2D Footwear except specific user interfaces.

ElitronCAD 2D Footwear can regenerate the digital version of the traditional manual shoe patterns. It can acquire manual shoe patterns by templates through manual digitization, DXF import or via scanner, background image etc. (“ElitronCAD 2D Footwear”, n.d.).

## 2.3 FootwearCAD by MiriSys Software s.r.o

FootwearCAD is another commercial product for computer aided designing. It works on Microsoft Windows platform. It is a professional 2D construction and grading system that was developed by MiriSys Software s.r.o. It is developed for manufacturer of all shoe and leather product types.

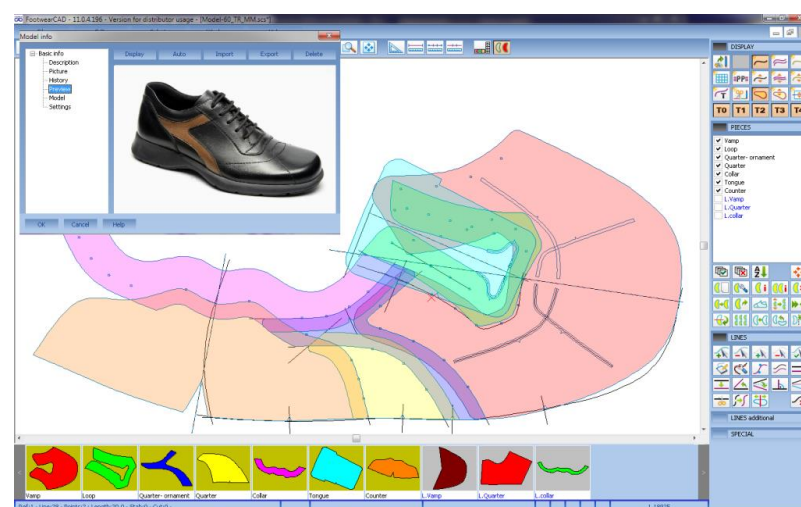


Figure 2.2 Designing Men's shoes with pieces in the basic size in FootwearCAD

It accepts patterns as input by digitizing, scanning or importing standard cad files. It is possible for the construction of pieces. Grading is possible with it. It can be used on cutting process that is nesting and cutting (“FootwearCAD”, n.d.).

## **2.4 AutoNester-L by Fraunhofer SCAI**

Fraunhofer SCAI develops AutoNester-L for automatic marker making on leather hides. It is available for Microsoft Windows platforms. It can be used with an application programming interface (API). It is organized as a Dynamic Link Library (DLL) to integrate AutoNester-L into their own CAD-software by CAD systems.

It is widely used in the leather, upholstery, and car manufacturing industry. It gains time and material with nesting any set of pieces within a very short time in optimal way, minimizing wasted material (“AutoNester-L”, n.d.). It uses search algorithms based on Simulated Annealing that is an algorithm locating a good approximation to the global optimum of a given function in a large search space (Kirkpatrick & etal., 1983).

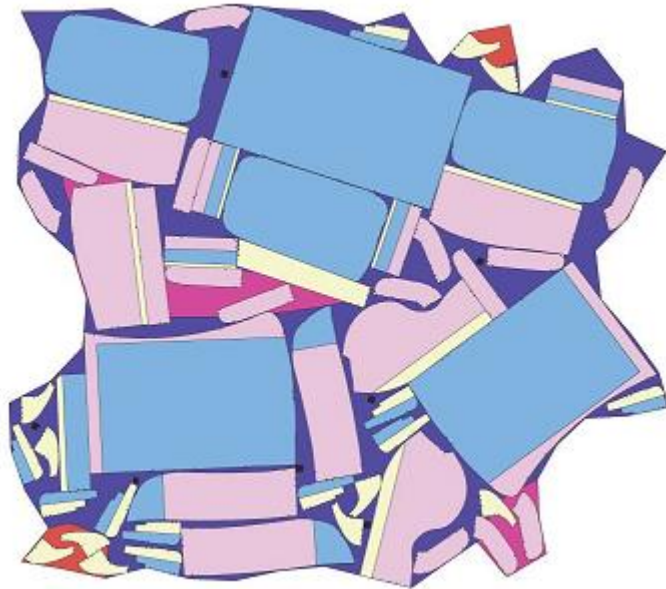


Figure 2.3 Locating 55 Furniture pieces with 84% efficiency with AutoNester-L

## **2.5 BobCAD-CAM for Router, WaterJet & Plasma by BobCAD-CAM Inc.**

BobCAD-CAM software solution is one of the commercial products. It was developed by BobCAD-CAM Inc in USA. It works on Microsoft Windows platforms. It is CNC software for routers, lasers, waterjet or plasma machines. It is suitable for artistic woodworking and machining jobs. It can import DXF file and then generate g-code to execute on the CNC machine.

It can import DXF, Solidwork, IGES, Parasolids, STEP, AutoCAD DWG, Rhino CAD 3DM, SAT/ACIS files (BobCAD-CAM CNC Software, n.d.).

## **2.6 Delcam CRISPIN PatternCut by Autodesk**

Another commercial product is Delcam CRISPIN PatternCut. It works on Microsoft Windows platform. It is a nesting system that was developed by Delcam acquired by Autodesk that is the owner of AutoCAD. It is possible to produce an efficient location with automatic nesting. PatternCut is a 2D pattern part nesting and cutting software. It is a part of Delcam CAD/CAM software package.

## **2.7 FreeCAD by Havre & etal.**

One of free cad software is FreeCAD. It is 3D parametric CAD modeler. As It has LGPL license, It is open source and allowing for 3rd party extensions and customization. As it is multiplatform, it runs on Microsoft Windows, Canonical Ubuntu, Apple Mac OSX, Redhat Fedora platforms and can be built on another Linux platform. Its initial release is published in 29 October 2002. FreeCAD is written in C++ and Python.

FreeCAD is aimed directly at mechanical engineering and product design but also fits in a wider range of uses around engineering, such as architecture or other engineering specialties (FreeCAD, n.d.). So not only the experienced CAD user can be use, but also the hobbyist can use.

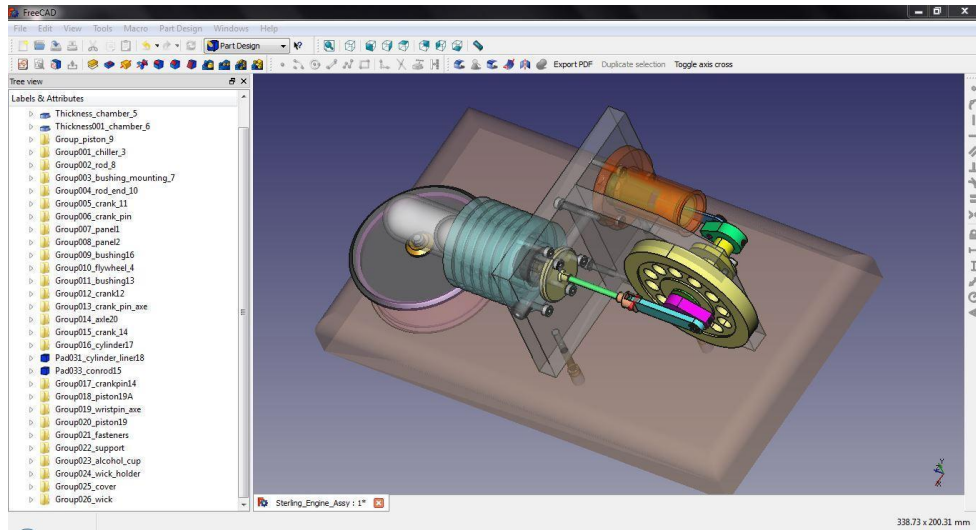


Figure 2.4 3D Model of Sterling Engine that designed with FreeCAD

## 2.8 LibreCAD by LibreCAD Community

LibreCAD is another free cad application that is sponsored by MacStadium. It is fully comprehensive 2D CAD application that has GPLv2 license. It works on GNU/Linux, Mac OS X, UNIX and Microsoft Windows operating systems. Its initial release is published in 28 December 2011. LibreCAD is developed by LibreCAD community with C++. LibreCAD uses the AutoCAD DXF file format internally for import and save files. And it allows to export many other file formats (LibreCad, n.g.).

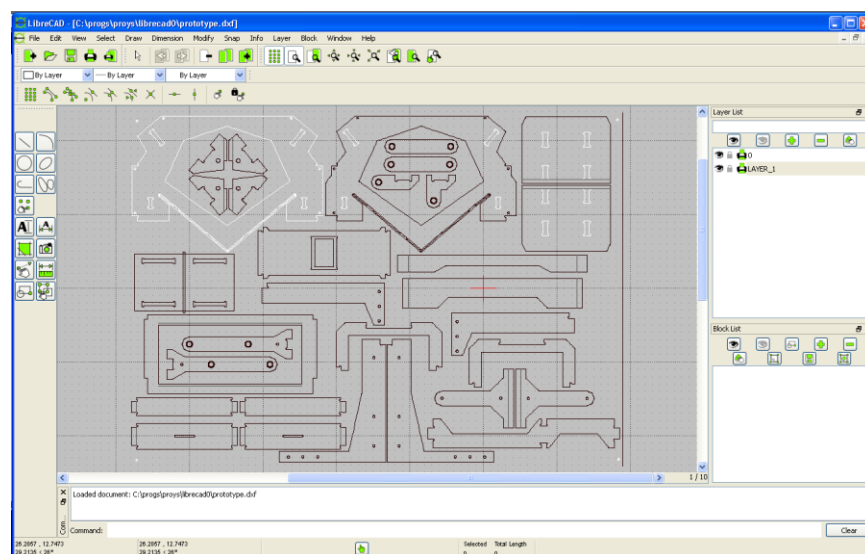


Figure 2.5 Editing a DXF file with LibreCAD

## 2.9 Motivation

Related works mentioned above are popularly run on Microsoft Windows. Only Caligola, FreeCAD and LibreCad run on Apple Mac OSX and GNU Linux. Most of them have proprietary licenses. But LibreCAD and FreeCAD have free licenses.

Applications have free licenses such as FreeCAD, LibreCAD and most of proprietary licensed applications are developed for general purpose. Users can design most of thing about patterns, but it can't design easily. Because, these applications have general purposes tools. The solution in this thesis gives an option to importing manual and traditional patterns to design. It eases the design process.

Most of applications which can import manual patterns have dependency on specific CNC machines. Mostly, producer of the CNC machines, develops own CAD/CAM applications such as ComelZ. This thesis gives a solution to the dependence with converting the design to G-Code standards for CNC machines and to ILDA standards for laser projections on the machines.

## CHAPTER THREE

### METHODS

This chapter firstly covers methods that are used in GCAD application. The common steps of cutting process on CNC machines are importing a manual pattern or creating new design, manipulating the design to use on a machine, and converting the design G-Code to execute on CNC machine. In this study, cutting and planning process is developed with three steps. Following figure illustrates the steps of the process.

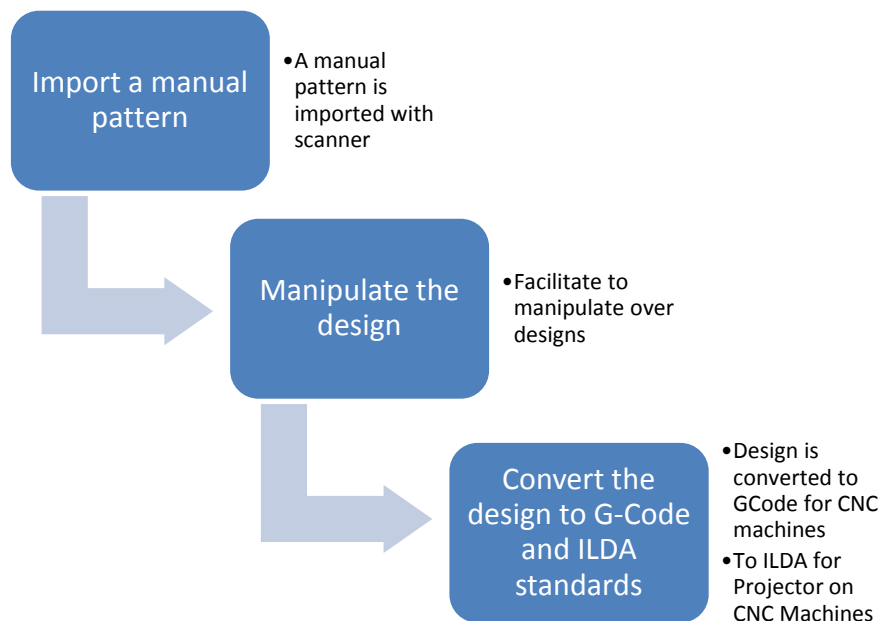


Figure 3.1 Steps of cutting process

### 3.1 Importing a Manual Pattern

Nowadays, patterns made with cardboard and so on is used in the cutting of leather goods in shoe manufacturing. To accelerate the cutting process, transferring into a computer-aided system of this method has become necessary. To facilitate transitional phase to the computer-aided system, it is essential for manual patterns to be importable and possible to manipulate over.

Importing process starts with firstly scanning optimum resolution (min 600 dpi) and converting to bitmap image (bmp, jpg, etc.). Image as input to import to application goes through the following process;

1. Detection of edge
2. Vectorizing
3. Adding to design

### ***3.1.1 Edge Detection***

An edge in an image is a significant local change in the image intensity. So edge detection is detection of edges in an image. The success of edge detection of a bitmap is related to resolution more than size. Because of that big size bitmap spent more time than small sized bitmap in edge detection, the input image is resized to area that is maximum 250000 px<sup>2</sup>. The image that is more sized 250000 px<sup>2</sup> is resized with using Resize method of OpenCV library with keeping the aspect ratio. For resizing, area interpolation is used.

For more accurate results from edge detection, image is converted to the simplest case as binary. So color tones are divided into 2 poles and edge detection become clearer. For converting to binary image, CvtColor method of OpenCV is used. Because CvtColor takes gray toned image, BgrToGray conversion is used.

Some of patterns may contain cavities that are difficult to parse from outer edge. To remove from the process of edge detection, Gaussian Smoothing and Otsu Threshold algorithms are used to the image.

Using Canny algorithm of OpenCV with 3x3 mask, lower 150 and upper 250 threshold parameters, edges of image are detected and come back to the process of final image.

So steps of edge detection are listed in order.

1. BgrToGray
2. Binary Threshold
3. Gaussian Smoothing
4. Otsu Threshold
5. Canny Edge Detector

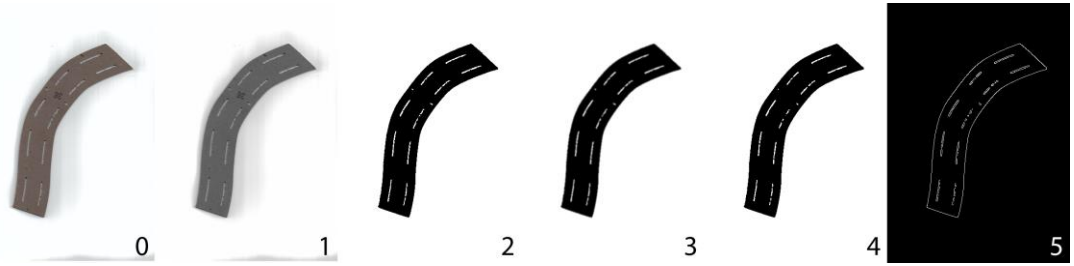


Figure 3.2 Results of edge detection steps

#### 3.1.1.1 BgrToGray

RGB image is also known as true color image. It is an image in which each pixel is specified by three values one each for the red, blue, and green components of the pixel scalar (Kumar & Verma, 2010). BGR image has three components like RGB, but components are blue, green, and red in order.

A grayscale image is also known as intensity, gray scale, or gray level image. It is simply one in which the only colors are shades of gray. Gray color is one in which the red, green and blue components all have equal intensity in RGB space.

According to Kumar and Verma (2010), BGR image is converted to grayscale image like that.

$$I_{BGR} = (F_B, F_G, F_R) \quad (3.1)$$

Where  $F_B$  is the intensity of the pixel (x, y) is the blue component,  $F_G$  is the intensity of pixel (x, y) in the green component,  $F_R$  is the intensity of pixel (x, y) in

the red component. Figure 3.4 shows  $F_B$ ,  $F_G$ , and  $F_R$  histograms of BGR image in figure 3.3.

$$I_Y = 0.333F_b + 0.5F_g + 0.1666F_r \quad (3.2)$$

Where  $F_b$ ,  $F_g$ , and  $F_r$  are the intensity of B, G and R component in order and  $I_Y$  is the intensity of equivalent gray level image of BGR image. Figure 3.5 show  $I_Y$  histogram of grayscale image in figure 3.3. Actually three of them are same, because of B, G and R components must be equal in a grayscale image.

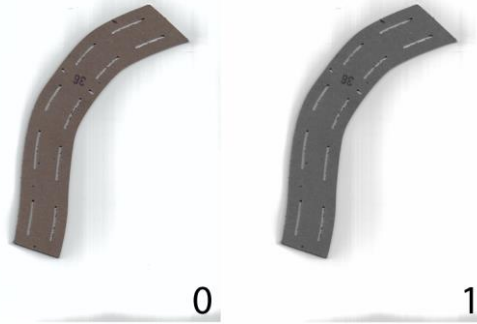


Figure 3.3 BGR and Grayscale image of manual shoe pattern

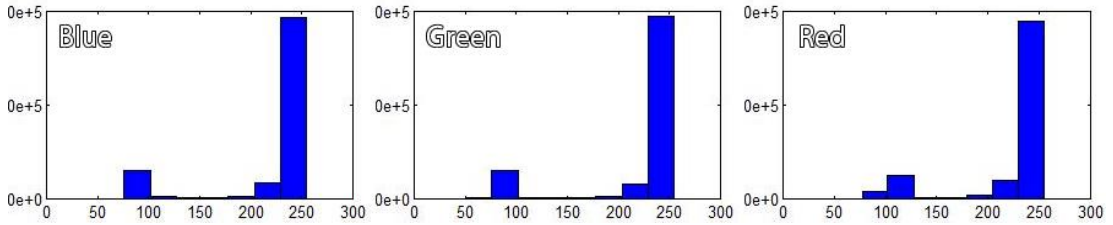


Figure 3.4 Histograms of BGR image

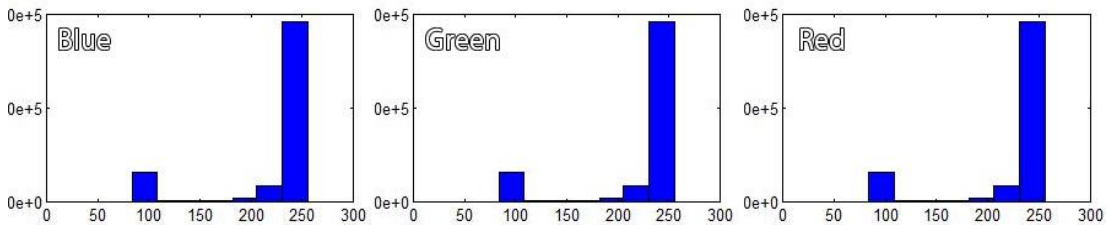


Figure 3.5 Histograms of grayscale image

### 3.1.1.2 Binary Threshold

Binary image contains only 0s and 1s, interpreted as black and white, respectively. For more accurate results from edge detection, grayscale image is converted to the simplest case as binary. Binary threshold is used for that. Maximum value is 255 of 0 – 255. It is 8-bit space which is chosen as maxval parameter. 128 is chosen as threshold value, because of it is middle value of  $2^8$  space. So grayscale tones are divided into 2 poles and edge detection is aimed to errorless.

Kamel and Zhao (1993) define Global Thresholding Technique like that.

$$dst(x,y) = \begin{cases} maxval & \text{if } src(x,y) > thresh \\ 0 & \text{otherwise} \end{cases} \quad (3.3)$$

Where if source pixel is bigger than threshold destination pixel is equal maxval else 0. Binary threshold is a global thresholding technique where maxval is 1.

$$dst(x,y) = \begin{cases} 1 & \text{if } src(x,y) > thresh \\ 0 & \text{otherwise} \end{cases} \quad (3.4)$$

Finally the formula has become with threshold value that is middle value of 0 -  $2^8$  space

$$dst(x,y) = \begin{cases} 1 & \text{if } src(x,y) > 128 \\ 0 & \text{otherwise} \end{cases} \quad (3.5)$$

Histograms in figure 3.6 show change intensity of an image to 0 and 255 as black and white. The histograms are generated from images in figure 3.7.

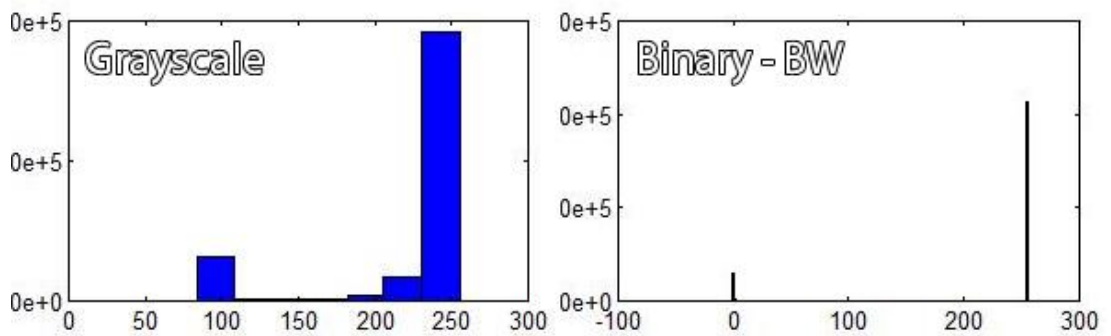


Figure 3.6 Histograms of grayscale and binary image

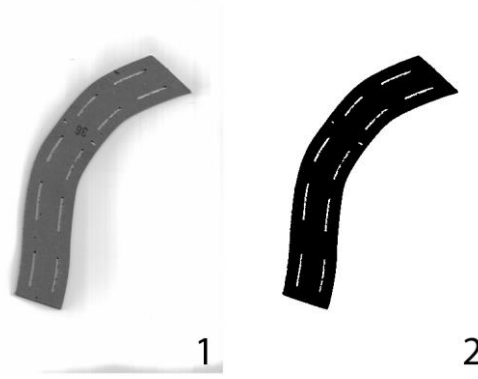


Figure 3.7 Conversion from grayscale to binary (black-white)

### 3.1.1.3 Gaussian Smoothing

It is one of methods of removing relatively little desirable particles in image. Those particles are not detected after image is smoothed. Gaussian Smoothing is also known as Gaussian Blur or Guassian Filter. It is the result of smoothing an image by a Gaussian function. Linear convolution with a 5x5 Gaussian kernel is used for Gaussian smoothing. According to OpenCV (n.d.), Gaussian kernel is computed with that formula.

$$G(x, y) = \frac{1}{2\pi\sigma^2} e^{-\frac{x^2+y^2}{2\sigma^2}}, \quad \sigma = 0.3 \left( \frac{n}{2} - 1 \right) + 0.8 \quad (3.6)$$

Where  $x$  and  $y$  are the distance from the,  $n$  is size width or height and  $\sigma$  is the standard deviation of the Gaussian distribution. Gaussian kernel must be square. And width or height must be odd number. So our 5x5 Gaussian kernel is the matrix.

$$\begin{bmatrix} 0.009355 & 0.023256 & 0.031498 & 0.023256 & 0.009355 \\ 0.023256 & 0.057816 & 0.078305 & 0.057816 & 0.023256 \\ 0.031498 & 0.078305 & 0.106055 & 0.078305 & 0.031498 \\ 0.023256 & 0.057816 & 0.078305 & 0.057816 & 0.023256 \\ 0.009355 & 0.023256 & 0.031498 & 0.023256 & 0.009355 \end{bmatrix} \quad (3.7)$$

As understood, placement of values in gaussian kernel, following figure is graphic of gaussian kernel with our parameters.

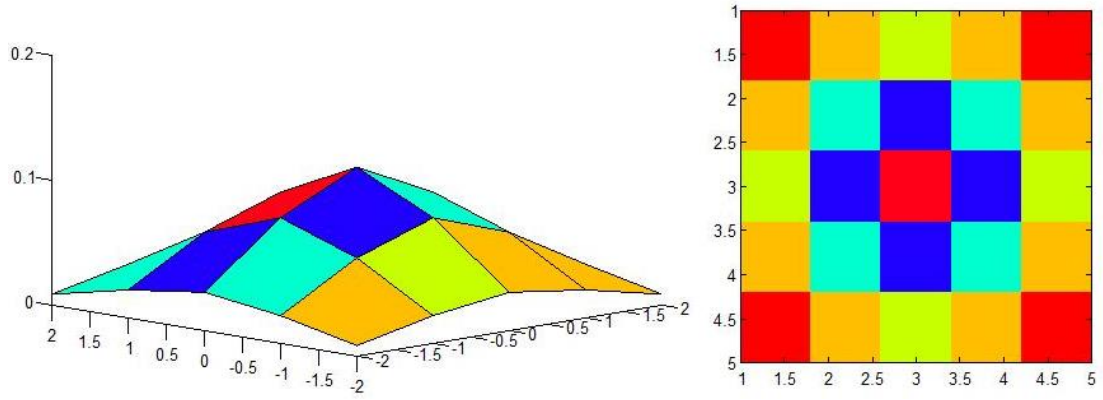


Figure 3.8 Pulse surface of 5x5 Gaussian filter with 1.25 sigma

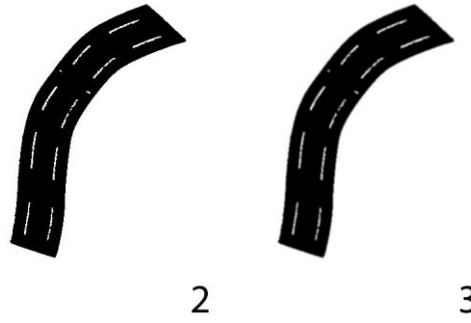


Figure 3.9 Smoothing with Gaussian filter

#### 3.1.1.4 Otsu Threshold

It is one of methods of removing relatively little desirable particles in image. It is a simple method, but difference of another is calculating threshold methods. Otsu threshold uses the threshold that is calculated by Otsu Algorithm.

Kamel and Zhao (1993) define Global Thresholding Technique like above. Otsu thresholding is used with max value of  $2^8$  spaces in solution of this thesis.

$$dst(x, y) = \begin{cases} maxval & \text{if } src(x, y) > thresh \\ 0 & \text{otherwise} \end{cases} \quad (3.8)$$

$$dst(x, y) = \begin{cases} 255 & \text{if } src(x, y) > thresh \\ 0 & \text{otherwise} \end{cases} \quad (3.9)$$

Threshold parameter must be calculated by Otsu algorithm. Otsu threshold is observed as splitting of pixels of an image to two classes  $C_0$  and  $C_1$  at gray level  $t$ . That is,  $C_0 = \{0, 1, \dots, t\}$  and  $C_1 = \{t + 1, t + 2, \dots, l - 1\}$ . Let  $\sigma_W^2, \sigma_B^2$ , and  $\sigma_T^2$  within-class variance, between-class variance, and the total variance, respectively. One of criterion functions of Otsu that is  $\eta = \sigma_B^2 / \sigma_T^2$  can determine a threshold to *thresh* parameter (Sahoo & etal, 1988).

$$thresh = \underset{t \in G}{\text{Arg Min}} \eta \quad (3.10)$$

where

$$\begin{aligned} \sigma_T^2 &= \sum_{i=0}^{l-1} (i - \mu_T)^2 p_i, & \mu_T &= \sum_{i=0}^{l-1} i p_i, \\ \sigma_B^2 &= \omega_0 \omega_1 (\mu_1 - \mu_0)^2, & \omega_0 &= \sum_{i=0}^t p_i, \\ \omega_1 &= 1 - \omega_0, & \mu_1 &= \frac{\mu_T - \mu_t}{1 - \omega_0}, \\ \mu_0 &= \frac{\mu_t}{\omega_0}, & \mu_t &= \sum_{i=0}^t i p_i \end{aligned} \quad (3.11)$$

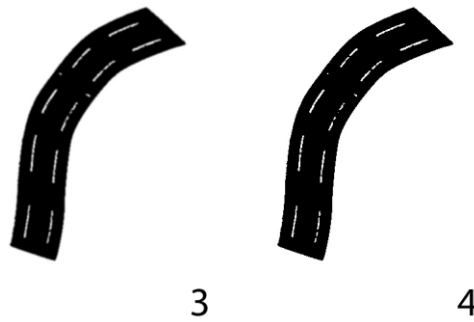


Figure 3.10 Otsu threshold (Otsu binarization) of smoothed image

### 3.1.1.5 Canny Edge Detector

Last and main step of edge detection method is Canny Edge Detector. Before steps from this are actually just cleanup and preparation to Canny. The Canny edge detector was developed by John F. Canny in 1986. It is an edge detection method that uses five sequential steps to detect a wide range of edges in images. Steps are listed below. (Demarchi & Pilon, 1986).

1. **Blurring:** smooth the image for decreasing noise. Gaussian filter is used for it. Filtering is applied with 3x3 kernel in solution of this thesis for best result. Gaussian 3x3 kernel is below.

$$\begin{bmatrix} 0.09284 & 0.119016 & 0.09284 \\ 0.119016 & 0.152574 & 0.119016 \\ 0.09284 & 0.119016 & 0.09284 \end{bmatrix} \quad (3.12)$$

2. **Determination of gradients:** Intensity gradient is computed with Sobel (Sobel, 1990).
  - a. Applying convolution mask couple in x and y axis with that masks

$$G_x = \begin{bmatrix} -1 & 0 & +1 \\ -2 & 0 & +2 \\ -1 & 0 & +1 \end{bmatrix}, \quad G_y = \begin{bmatrix} -1 & -2 & -1 \\ 0 & 0 & 0 \\ +1 & +2 & +1 \end{bmatrix} \quad (3.13)$$

- b. Calculating gradient weight and way with those formulas

$$G = \sqrt{G_x^2 + G_y^2}, \quad \theta = \arctan\left(\frac{G_y}{G_x}\right) \quad (3.14)$$

$\theta$  is rounded to one of  $0^\circ$ ,  $45^\circ$ ,  $90^\circ$  or  $135^\circ$  angles

3. **Non-Maximum Suppression:** In edge detection, only local maximum points can be detectable as edges.
4. **Double thresholding:** for decreasing still existing noise, double thresholds are applied.

5. **Hysteresis:** suppress the low points to lower and high ones to higher. There is 3 zones in intensity area that is split by upper and lower threshold. Those can be named as lower, middle, and upper zone. There is 3 conditions for edge decision of a pixel.

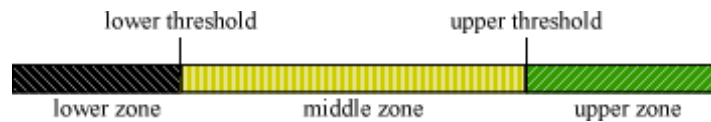


Figure 3.11 Zones of intensity gradient area in hysteresis

- If it is in upper zone, mark as an edge
- If it is in middle zone, don't mark as an edge
- If it is in lower zone and connected a pixel in upper zone, mark as an edge ("Canny Edge Detector", n.d.).

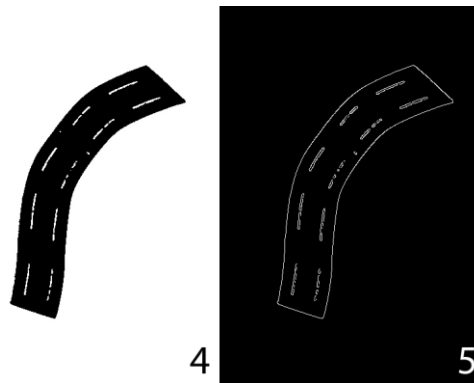


Figure 3.12 Result of OpenCV Canny Method

### 3.1.2 Vectorize

Edge detected bitmap image that is smoothed, scalable and based on geometrical primitives is more important for CAD/CAM application and the cutting machine. It can be defined as vectorization and is also known as image tracing. Before defining the vectorization, raster and vector image must be defined.

Raster image is a structure as matrix of pixel that generally contains color info in a color model like RGB, CMYK etc. BMP, JPEG, PNG and GIF file types which are common image file are stored an image as a raster image. They depend on resolution, and they are not able to scale up without loss of quality. Storing and modifying image data as a matrix of pixel is easy, because it can be iterate with an index. But it is costlier process in pixel by pixel with large sized images. In addition to this, displaying of a raster image has a less cost.

Vector image is a graphic which contains some geometrical primitives about how to look like. A vector image includes points, lines, polygons, Bezier curves, circles, ellipses and more as a definition, but never includes pixels. Some of vector image types such as SVG files are based on xml standard. Because they are just basically an xml file. They are generally rendered by viewer such as a browser, when they are displayed. Because of that rendering is processed by viewer, scaling or modifying does not make a loss of quality. Vector images give just instructions, renderer build image. DWF (Design Web Format), DWG, DXF (Drawing Exchange Format) those are 3D, and AI (Adobe Illustrator), CDR (CorelDraw), PPT (Microsoft PowerPoint), SVG (Scalable Vector Graphics), XPS (XML Paper Specification) those are 2D are some of vector image file types.

So vectorization is an act to change structure of raster image to a vector image. Advantages of vectorization are

- CNC machine generally uses geometrical primitives.
- Modifying vector image is more suitable and user-friendly.
- Such as scaling, resizing, rotating operations don't less mean from image.
- Reduces cost in magnification in CAD application.
- Smaller file sizes.
- More appropriate for compression

Table 3.1 Vectorization Softwares

	Creator	Released	Price	Licence
AutoTrace	Martin Weber	1998	free	GPL
Inkscape	The Inkscape Team	2003	free	GPL
MagicTracer	Elgorithms	2005	\$59.95	Proprietary
Potrace	Peter Selinger	2001	free	GPL
Scan2CAD	Avia Systems	1998	\$699	Proprietary
VectorMagic	Cedar Lake Ventures	2007	\$295.00	Proprietary
Vextractor	VextraSoft	2000	\$49.95	Proprietary
WinTopo	SoftSoft	1998	\$340	Proprietary

Because of licensed with GPL and recent library of vectorization, potrace algorithm in Potrace project is used in vectorization step of solution. Peter Selinger defines Potrace as a polygon-based tracing algorithm (Selinger, 2003). Potrace algorithm converts a raster image to vector image in 4 steps.

1. Extract paths from edges between black and white zones.
2. Approximate to an optimal polygon
3. Convert each polygon to a smooth outline
4. Join sequential Bezier curves together to optimize
5. Generated an output in required format.

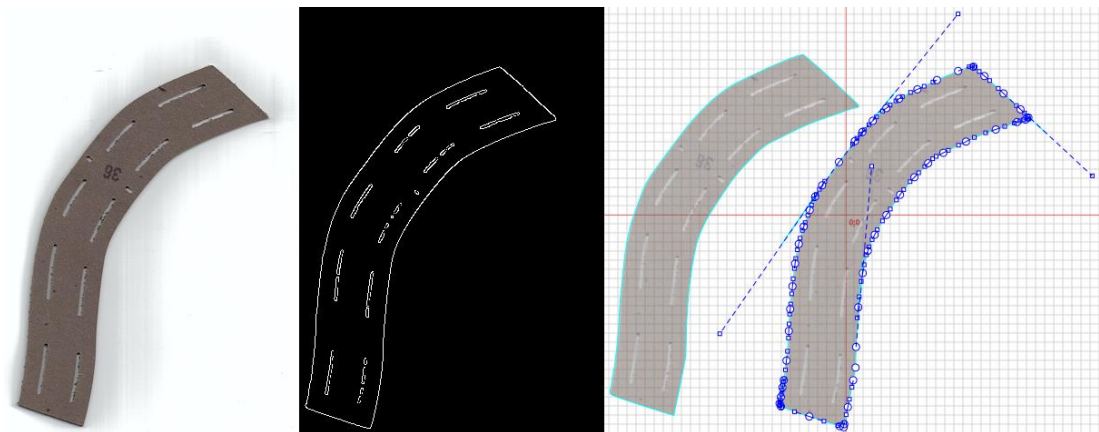


Figure 3.13 Vectorization of manual shoe pattern in some step

### 3.2 Manipulating the Design

Design file contains shapes as curves, rectangles, ellipse, and text components. Modifying of the design is manipulating the components with control points and endpoints of shapes. Control points and endpoints store absolute or relative coordinates to render by interpreters.

#### 3.2.1 Curve

A Bezier curve is a parametric curve that is generally used in vector graphics to model curves, because of scalability. Bezier curves have no limits and they are amendable. Most of Vector graphics editors calls Bezier curves as “Path”. A path as a shape of the design contains Bezier curve segments. Those segments are linear Bezier, quadratic Bezier, cubic Bezier and arc segments.

##### 3.2.1.1 Linear Bezier Curve

There are two end points for linear Bezier curve. They are P1 and P2 respectively.

$$B_1(t) = (1 - t)P_1 + tP_2, \quad B'_1(t) = P_2 - P_1, \quad B''_1(t) = 0 \quad (3.15)$$

##### 3.2.1.2 Quadratic Bezier Curve

There are two endpoints and one control point for quadratic Bezier curve. They are P1, P2, and Q.

$$\begin{aligned} B_2(t) &= (1 - t)^2P_1 + 2t(1 - t)Q + t^2P_2, \\ B'_2(t) &= -2[(1 - t)P_1 - (1 - 2t)Q - tP_2], \\ B''_2(t) &= 2[P_1 - 2Q + P_2] \end{aligned} \quad (3.16)$$

### 3.2.1.3 Cubic Bezier Curve

There are two endpoints and two control points for cubic Bezier curve. They are  $P_1$ ,  $P_2$ ,  $Q_1$ , and  $Q_2$  respectively.

$$\begin{aligned}
 B_3(t) &= (1-t)^3 P_1 + 3t(1-t)^2 Q_1 + 3t^2(1-t) Q_2 + t^3 P_2, \\
 B'_3(t) &= -3[(1-t)^2 P_1 - (1-t)(1-3t) Q_1 - t(2-3t) Q_2 \\
 &\quad - t^2 P_2], \\
 B''_3(t) &= 6[(1-t) P_1 - (2-3t) Q_1 + (1-3t) Q_2 + t P_2]
 \end{aligned} \tag{3.17}$$

### 3.2.1.4 Elliptical Arc Curve

Elliptical arc segment represents an elliptical arc between two points  $P_1$  and  $P_2$ . The arc is drawn from  $P_1$  to  $P_2$ . It uses x axis rotation for rotating arc as an ellipse with maintaining  $P_1$  to  $P_2$ . In other words, elliptical arc is an ellipse that part of it is cut by symmetry from  $P_1$  and  $P_2$  of it.

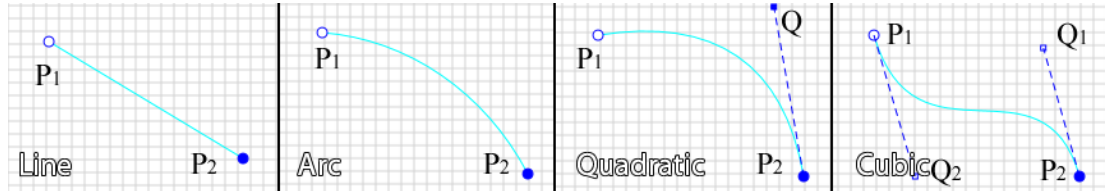


Figure 3.14 Types of curve segments

### 3.2.2 Rotating Curve

Gonzalez and Woods (2007) defines following equations for rotation by an angle  $\theta$  of 2D shape around the origin point.

$$x = x' \cos \theta - y' \sin \theta, \quad y = x' \sin \theta + y' \cos \theta \tag{3.18}$$

where  $(x, y)$  are rotated coordinates and  $(x', y')$  are the coordinates before rotation. When translation is applied to equation, the equation will provide rotating by an angle  $\theta$  around a center point which is formed by  $(C_x, C_y)$ .

$$\begin{aligned} x &= (x' - C_x)\cos\theta - (y' - C_y)\sin\theta + C_x, \\ y &= (x' - C_x)\sin\theta + (y' - C_y)\cos\theta + C_y \end{aligned} \quad (3.19)$$

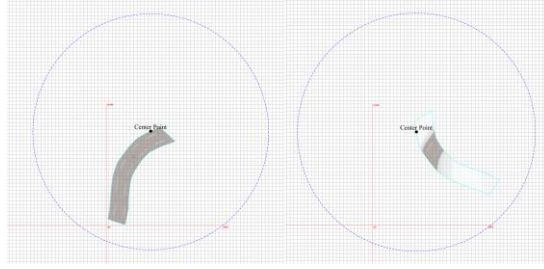


Figure 3.15 Rotating of Bezier curve

### 3.2.3 Scaling Curve

Scaling around the origin point is applied by following equations.

$$x' = S_x x, \quad y' = S_y y \quad (3.20)$$

where  $(x, y)$  are unscaled coordinates,  $(x', y')$  are scaled coordinates, and  $S_x, S_y$  are scaling ratios on width and height respectively. Following equations are scaling equations with translation to scale around a center point which is formed by  $(C_x, C_y)$ .

$$x' = S_x(x - C_x) + C_x, \quad y' = S_y(y - C_y) + C_y \quad (3.21)$$

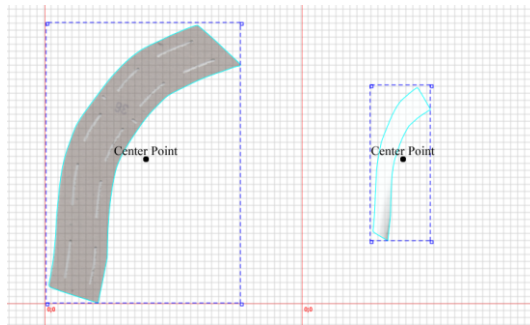


Figure 3.16 Scaling of Bezier curve

### 3.2.4 Locating Curve on Axis

Some process such as mirroring, scaling to different sizes in shoe industry needs an axis. Pattern is mirrored from the axis. Accordingly, scaling accepts an axis. But this axis is calculated and located with selecting a center point of shape by user. Curve on axis is located with following steps.

1. Draw the first line with selecting two points from border by user

$$C_{1x} = (P_{1x} + P_{2x})/2, \quad C_{1y} = (P_{1y} + P_{2y})/2 \quad (3.22)$$

where  $C_{1x}, C_{1y}$  are center point of first line,  $P_{1x}, P_{1y}, P_{2x}, P_{2y}$  are points which first line is drawn with.

2. Draw the second line with selecting two points from border by user

$$C_{2x} = (P_{3x} + P_{4x})/2, \quad C_{2y} = (P_{3y} + P_{4y})/2 \quad (3.23)$$

where  $C_{2x}, C_{2y}$  are center point of first line,  $P_{3x}, P_{3y}, P_{4x}, P_{4y}$  are points which first line is drawn with.

3. A line is drawn by two points that are center of the first and second lines and accepted as an axis.

$$C_x = (C_{1x} + C_{2x})/2, \quad C_y = (C_{1y} + C_{2y})/2 \quad (3.24)$$

4. Rotate the axis around point  $C$  to default axis of the design.

$$\text{atan2}(y, x) = \begin{cases} \arctan \frac{y}{x} & x > 0 \\ \arctan \frac{y}{x} + \pi & y \geq 0, x < 0 \\ \arctan \frac{y}{x} - \pi & y < 0, x < 0 \\ \frac{\pi}{2} & y > 0, x = 0 \\ -\frac{\pi}{2} & y < 0, x = 0 \\ \text{undefined} & y = 0, x = 0 \end{cases} \quad (3.25)$$

$$\theta = \text{atan2}(C_{2y} - C_y, C_{2x} - C_x) \quad (3.26)$$

where  $\theta$  is the angle which will use in rotate function that defined in equation 3.10.

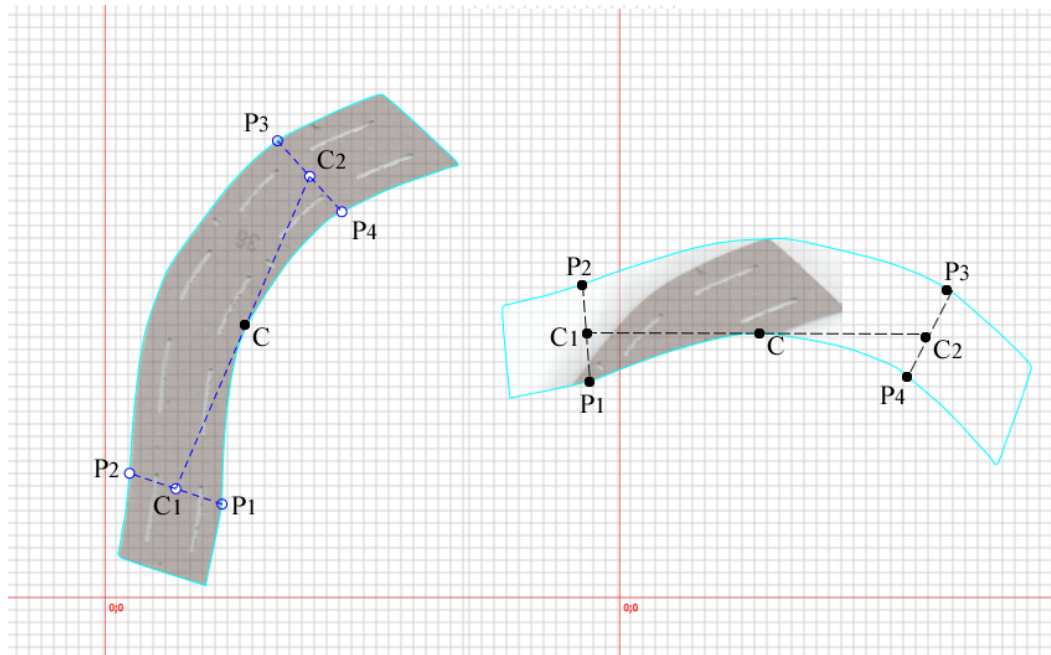


Figure 3.17 Locating curve on axis

### 3.2.5 Rectangle

Rectangle is a polygon that has four right angles. Square is also a rectangle. Scaling a rectangle without lost characteristic that the owner of four right angles is possible with only one control point.

### 3.2.6 Ellipse

Ellipse has two axis that are called major and minor axis. Changing length of one of axis scales the ellipse. So scaling an ellipse is possible two control point for width and height.

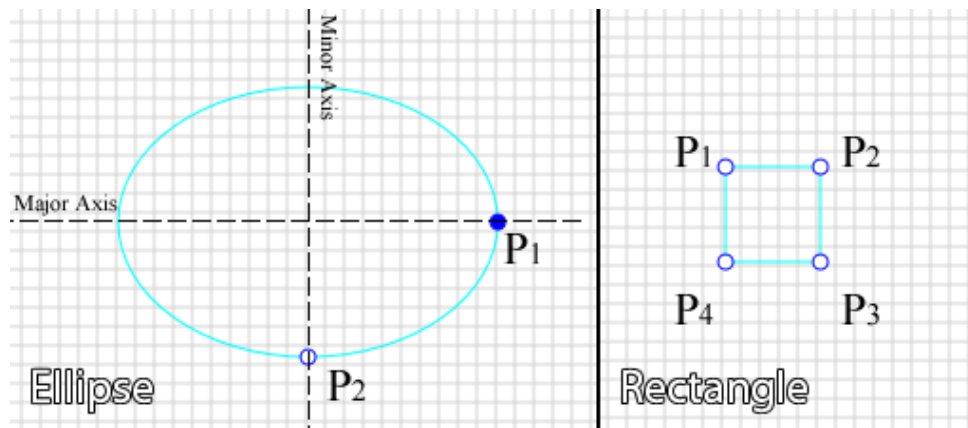


Figure 3.18 Ellipse and Rectangle

## 3.3 Converting the Design to G-Code and ILDA

### 3.3.1 G-Code

G-code is also known as RS-274. It is wide-used name for numerical programming language that is used in CNC machines. G-code is sometimes called G programming language. RS-274 is founded by Joseph Gerber. So its file format is called with Gerber. RS-274 has many variants. RS-274X and RS-274-D are two of them. RS-274-D is Standard Gerber, and is obsolete and deprecated. RS-274X is called as Extended Gerber, and it is latest Gerber format.

The Gerber format is a vector graphic format that is 2D and resolution-independent. Gerber format defines four types of graphics objects (“The Gerber Format Specification”, n.d.).

1. Line that named as draw
2. Arc that is a circular arc. Because not an elliptical arc in our solution, elliptical arc must be derived to a circular arc.
3. A flash that is a replication of a basic geometric shape.
4. A region that is an area of declared by a contour.

Because, the Gerber format is a vector graphic, approximation from graphic object to graphic object of Gerber is easy. The approximation is necessary for converting from the design to g-code. And It is almost and practically a converting of syntax.

Table 3.2 An example of G-Code: A Square box.

G04 A square boxes*	G04 function code is used for comments <b>&lt;Comment&gt;: G(4 04)&lt;Comment content&gt;*</b>
%FSLAX25Y25*%	Specify the format of the coordinate number. Omit leading zeroes, absolute notation. 2 digit in integer, 5 digit in decimal part <b>&lt;FS command&gt;: FS(L T)(A I)X&lt;Format&gt;Y&lt;Format&gt;*</b>
%MOMM*%	Set the units as MM used for coordinates and sizes. <b>&lt;MO command&gt;: MO(IN MM)*</b>
%TF.MD5,e4d909c290d0fb1ca068ffaddf22cbd0*%	Set MD5 file attribute for checking integrity <b>&lt;TFcommand&gt;: TF&lt;AttributeName&gt;[,&lt;AttributeValue&gt;]</b>
%LPD*%	Set polarity level as dark <b>&lt;LP command&gt;: LP(C D)*</b>
%ADD10C,0.010*%	Create an aperture with coded as D10 and 0.01 mm circle <b>&lt;AD command&gt;: ADD&lt;D-code number&gt;&lt;Aperture name&gt;[,&lt;Modifiers set&gt;]*</b> <b>&lt;Modifiers set&gt;: &lt;Modifier&gt;{X&lt;Modifier&gt;}</b>
D10*	Select D10 as current aperture.

Table 3.2 An example of G-Code: A Square box. (Continue)

X0Y0D02*	Move to (0,0) <Interpolation>: [G(1 01 2 02 3 03)][<Coordinate data>D(1 01 2 02)]*
G01*	Set linear interpolation
X500000Y0D01*	Draw to (5, 0) with D10
Y500000D01*	Draw to (5, 5) with D10
X0D01*	Draw to (0, 5) with D10
Y0D01*	Draw to (0, 0) with D10
M02*	End of file

### 3.3.2 ILDA

Project supported cutting machine is generally used laser projectors that are programmable with a format such as ILDA for displaying the patterns or shapes. ILDA is called International Laser Display Association which is worldwide non-profit association and they are working for enhancing the use of laser displays. ILDA developed an image format to transfer between laser projectors and systems (Heminover & Murphy, 2006).

ILDA is a raster graphic format. So, the design in thesis solution that is a vector graphic must be converted to a raster graphic to format as ILDA. In other words, the polygonal approximation of a Bezier curve must be taken. Since a Bezier converted with optimum polygons, it gives a dot matrix to use for a raster image.

## **CHAPTER FOUR**

### **APPLICATION**

This application is developed for CNC Routers which do 2D manufacturing. And it is called as GCAD. Users can design easily a pattern with this application. Because the application provides an option to importing manual and traditional patterns to design. So it eases the design process.

GCAD does not depend to a CNC machine, because of converting the design to G-Code standards for CNC machines and to ILDA standards for laser projections on the machines.

The GCAD is used for importing from manual patterns, editing the pattern and exporting to CNC machines in shoe leather industry. With this application, creation or modification of a pattern in 2D perspective was made possible. GCAD was developed on .NET 4.0 framework with C#; therefore it needs a Windows machine or any OS that is fully compatible with .NET 4.0. Used methods to construct the GCAR were explained in Chapter 3. In this chapter, used development tools, the capabilities and usage of GCAD will be explained.

In this thesis, Microsoft Visual Studio, Extended WPF Toolkit are used to develop GCAD and FreeMat to draw histograms of images that are converted by vectorization.

#### **4.1 Microsoft Visual Studio**

Microsoft Visual Studio is an IDE that was developed by Microsoft. It can be used to develop many applications such as WPF, WinForm, WCF, ASP.NET for operating on Microsoft Windows. GCAD was developed based .NET 4.0 with C# as a WPF application.

ASP.NET Web applications, XML web services, desktop and mobile applications can be developed with Visual Studio. It shares tools and eases for solutions that has mixed languages. The solutions may include more than one types of languages. Visual studio provide the .NET Framework for the Visual Basic, Visual C#, and Visual C++

.NET Framework is a framework that contains a large class library. The library is named as Framework Class Library. Two different programming languages can use the same kind of data structures in NET Framework. The framework provides language interoperability. The execution of .NET programs are managed by a virtual machine component that is named as Common Language Runtime. It is reminiscent of Java virtual machine (JVM), Dalvik or Android Runtime (ART).

Code editor of Visual Studio has several characteristics in common code editors. It supports syntax highlighting and code completion. IntelliSense is code completion feature of Visual Studio. It makes faster coding to prevent typos. It supports variables, methods, functions, and LINQ queries.

Visual Studio has own debugger. The debugger can attach to running processes and debug and monitor those. It can also create memory dump for debugging afterward. It can also debug multi-threaded programs. The debugger lets developer edit code and apply to the process and invoke some functions manually during debugging.

Microsoft Visual Studio has some WYSIWYG editor such as Windows Forms Designer, WPF designer, Web designer, class designer, data designer, mapping designer etc.

It is compatible with revision control systems. It can integrate Team Foundation Server with Team Explorer tool window. Apache Subversion can also be used in Visual Studio with plugin that is named as VisualSVN.

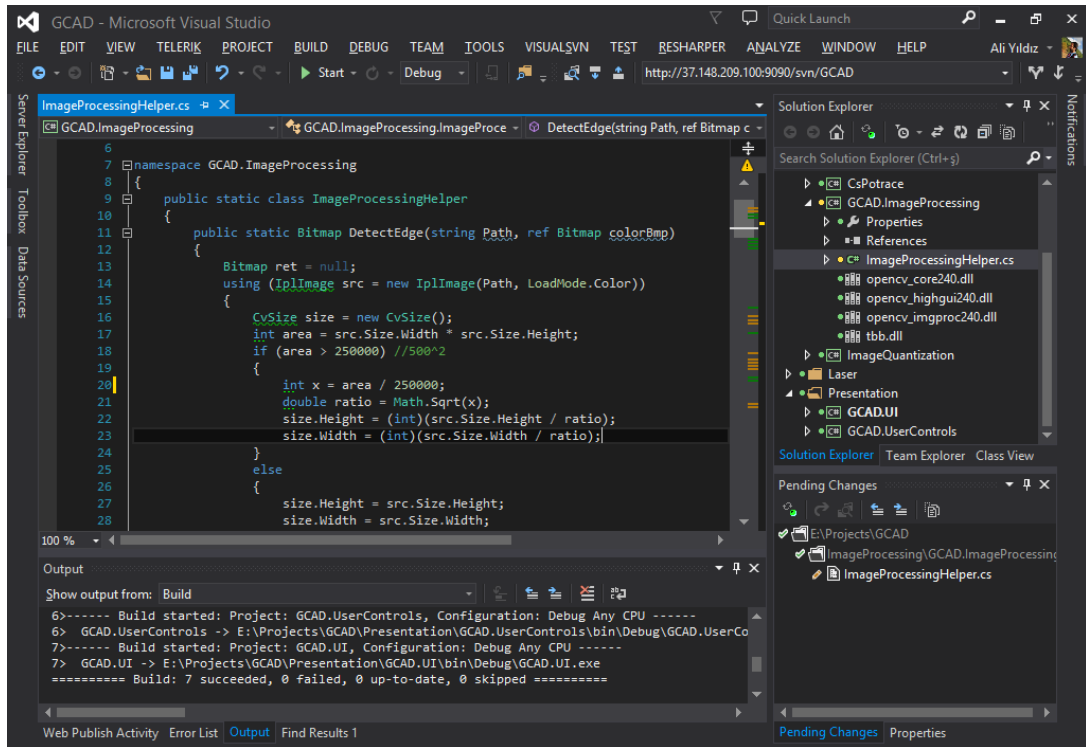


Figure 4.1 GCAD solution on Microsoft Visual Studio Professional 2013

## 4.2 Extended WPF Toolkit

Extended WPF Toolkit Community Edition is framework which has huge collection of WPF controls. GCAD used a tabbed dock structure that is named as Xceed Avalondock in this framework.

The Community Edition of Extended WPF Toolkit has Ms-PL(Microsoft Public License). Ms-PL can be summarized with item d in the license.

(D) If you distribute any portion of the software in source code form, you may do so only under this license by including a complete copy of this license with your distribution. If you distribute any portion of the software in compiled or object code form, you may only do so under a license that complies with this license (“Microsoft Openness”, n.d.).

The summary of the Ms-PL is that anybody can freely use or modify the source under this license. When code which was released under this license was used or modified, it has to be provided under the same license. So a library under this license is used in a code portion, rest of code doesn't have to be released under that license. But the code portion must be released under this license.

The following controls in Community Edition of Extended WPF Toolkit can be used freely ("Compare Extended WPF Toolkit Editions", n.d.).

Table 4.1 Controls in Community Edition of Extended WPF Toolkit

AvalonDock	AutoSelectTextBox	BusyIndicator	ButtonSpinner
ByteUpDown	Calculator	CalculatorUpDown	CheckComboBox
CheckListBox	ChildWindow	CollectionControl	CollectionControlDialog
ColorCanvas	ColorPicker	DataGrid	DateTimePicker
DateTimeUpDown	DecimalUpDown	DoubleUpDown	DropDownButton
IntegerUpDown	LongUpDown	Magnifier	MaskedTextBox
MessageBox	MultiLineTextEditor	PieChart	PrimitiveTypeCollEditor
PropertyGrid	RangeSlider	RichTextBox	RichTextBoxFormatBar
ShortUpDown	SingleUpDown	SplitButton	SwitchPanel
TimelinePanel	TimePicker	TimeSpanUpDown	ValueRangeTextBox
WatermarkTextBox	WindowContainer	WindowControl	Wizard
Zoombox	Windows 8 Theme		

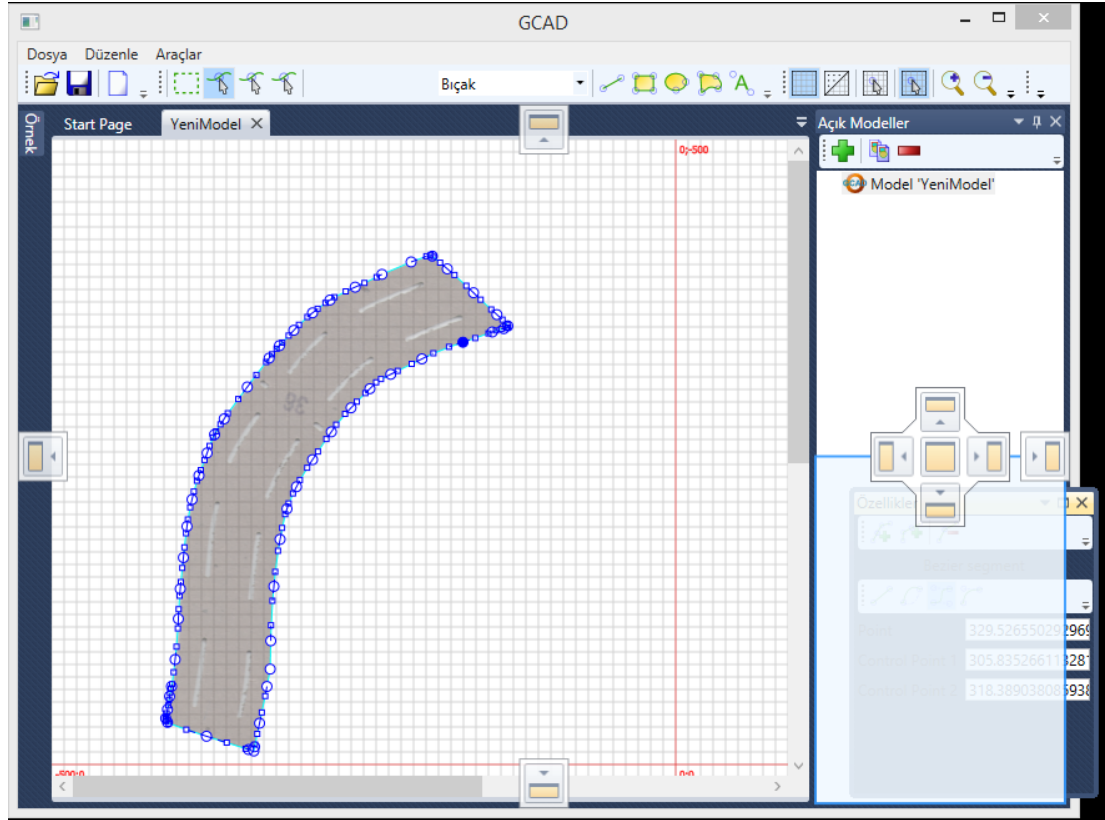


Figure 4.2 Pinnig of Avalondock pane on GCAD

### 4.3 FreeMat

FreeMat is a numerical computing environment that has GPL license for engineers, scientist, and student. It is alternative to commercial systems such as MATLAB. FreeMat was used, when histogram and surface diagrams are created.

GPL is known as General Public License. This license has developer's sights set on creating free software. Free Software Foundation that is creator of GPL abstract this license with this passage.

Nobody should be restricted by the software they use. There are four kinds of freedom that every user should have:

- The freedom to use the software for any purpose,
- The freedom to change the software to suit your needs,

- The freedom to share the software with your friends and neighbors, and
- The freedom to share the changes you make.

When a program offers users all of these freedoms, we call it free software (Smith B., 2014).

The summary of the GPL is that anybody can freely use, change, share the everything about the program under this license.

FreeMat is a MATLAB clone like GNU Octave, Scilab etc. It purposes to create alternatives to MATLAB, to break monopoly of MATLAB, and to serve as free and costless alternative to users which need a numerical computing environment.

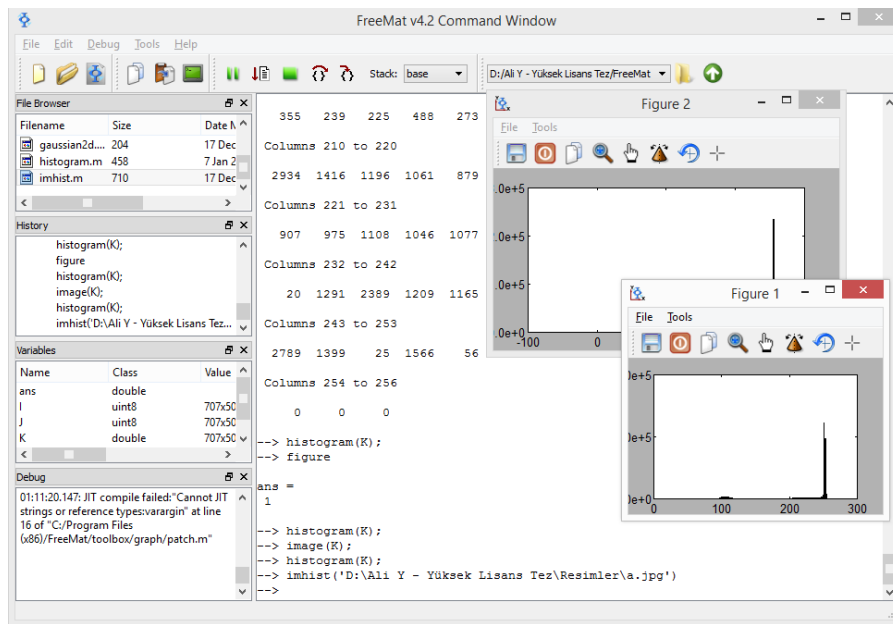


Figure 4.3 Histogram with FreeMat

#### 4.4 Application Capabilities

Developed application contains three main modules. These are

- Manual Pattern Importer
- Design Area
- Exporting to CNC

#### 4.4.1 Manual Pattern Importer

This module was mostly explained in Section 3.1. Manual Pattern Importer does its task in the background of application. Right clicking on the Model Item in Opened Models pane and clicking “Add a part from scanned image” starts this module. It is shown in following figure. User selects a scanned image of manual pattern. The image is vectorized and then added to design tool.

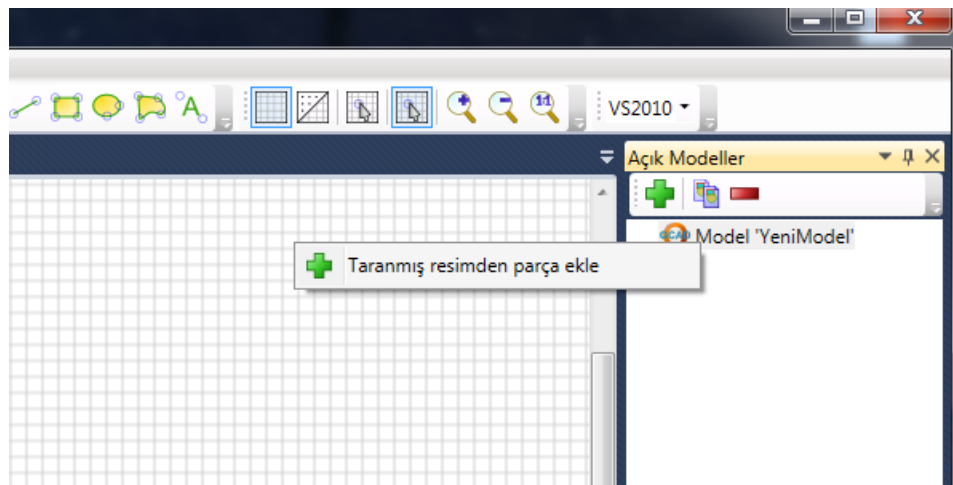


Figure 4.4 Manual pattern importer

#### 4.4.2 Design Area

GCAD Design area can be possible to manipulate the design. There are edit, rotate, scale modes. In scale mode, selected shape can be scaled with given ratio. In rotate mode, selected shape can be rotated with given angular.

In edit mode, a new shape can be created or selected shape can be edited with five tools.

1. New Line
2. Rectangle
3. Ellipse
4. Curve
5. Text

In edit mode, if selected shape is a curve, endpoints and control points become selectable. Selected endpoint can make transition between line, arc, Bezier, and quadratic Bezier types of segments.

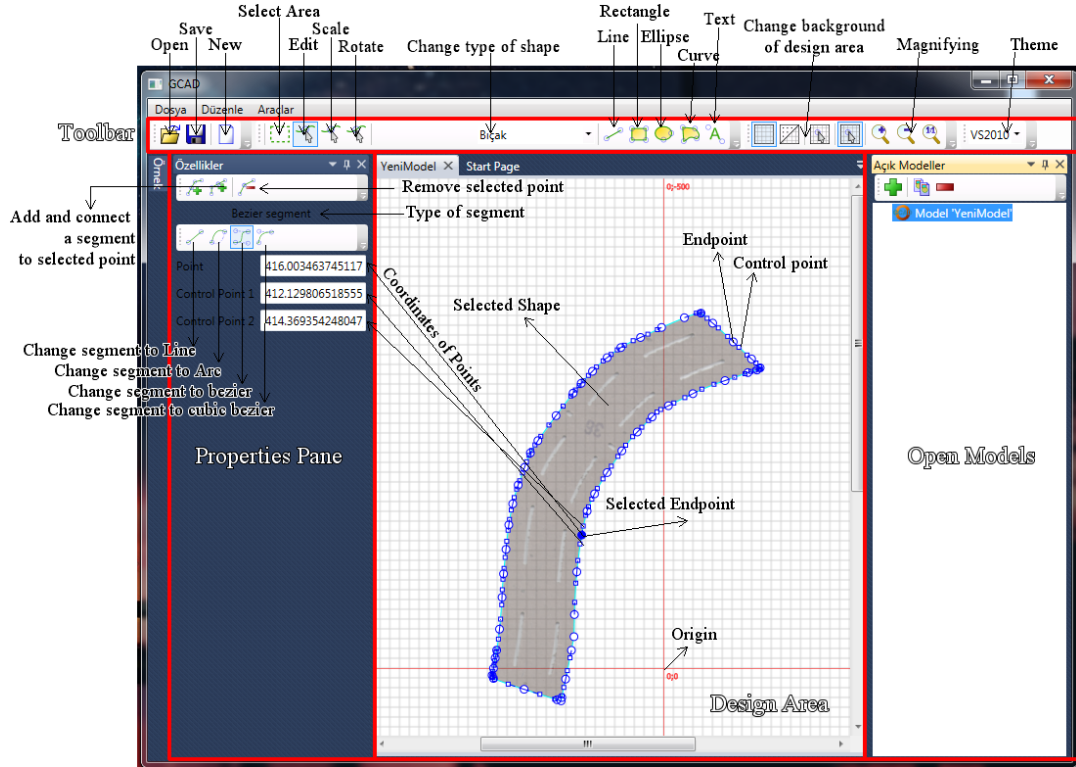


Figure 4.5 Design area

#### 4.4.2.1 Open

The open button opens GDZ files and prepares the design area. The GDZ file is a GCAD project file. It is actually a ZIP compressed package file. And it contains 2 files and 1 directory. The directory named as images includes images which are used in drawings.

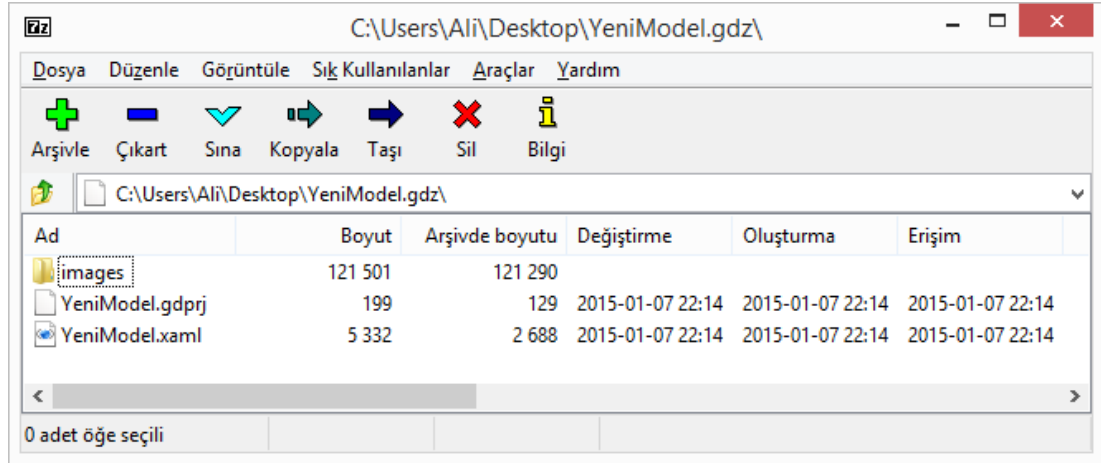


Figure 4.6 GCAD project file as a ZIP

The GDPRJ is main file of the package and a XML file. The file with GDPRJ extension is a well formed XML. This file is firstly loaded by the application. It contains definitions of the project such as version of file, name of project, file path of vector image. The FileVersion tag in following figure defines the version of the GDPRJ file. According to this version number, GCAD application renders the GDPRJ file. Name of project is included in ProjectName tag. XAMLFilePath shows path of vector image file.

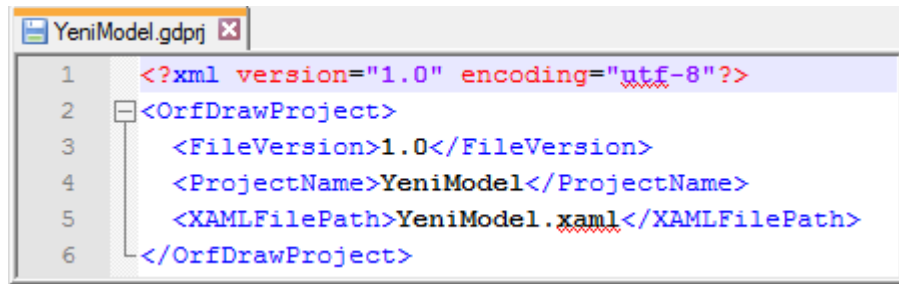


Figure 4.7 A GDPRJ file

The XAML file is a vector image file and type of XAML. It contains types of System.Windows.Media namespace in .NET Framework 4 including drawings, text, and audio/video content. GCAD renders this file and prepares the design area with using parameters and types in the file.

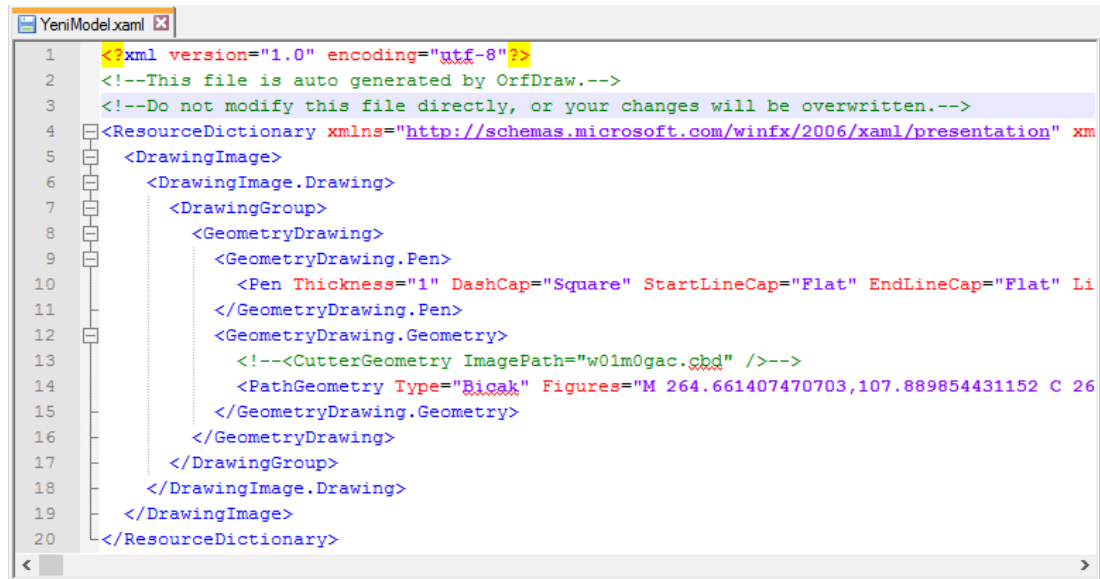


Figure 4.8 A XAML file

#### 4.4.2.2 Save

The save button saves the design as GDZ format. It firstly creates a XML containing definitions of project and saves to a GDPRJ file in temporary folder of Microsoft Windows. Then it converts the design to a well formed XML as a vector image and saves to a XAML file in temporary folder which GDPRJ file is saved in. Copy all necessary raster image files to the directory. In the end, all file of the project are compressed as zip file with GDZ extension.

#### 4.4.2.3 New

The new button creates a new design file and prepares the design area. The application asks a project name for user. Then it creates a temporary directory in temporary directory of Windows.

New tab is added in GUI. Each tabs contains a pattern design. A tab contains a blank design area. The area is used for designing the pattern of material that will be cut. Guide lines are drawn in horizontal and vertical for easing to draw a design. In addition, an item is added to “Open Models” pane in GUI for managing projects.

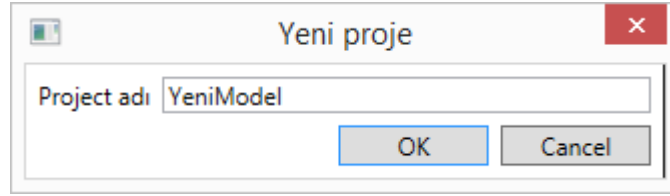


Figure 4.9 New project dialog

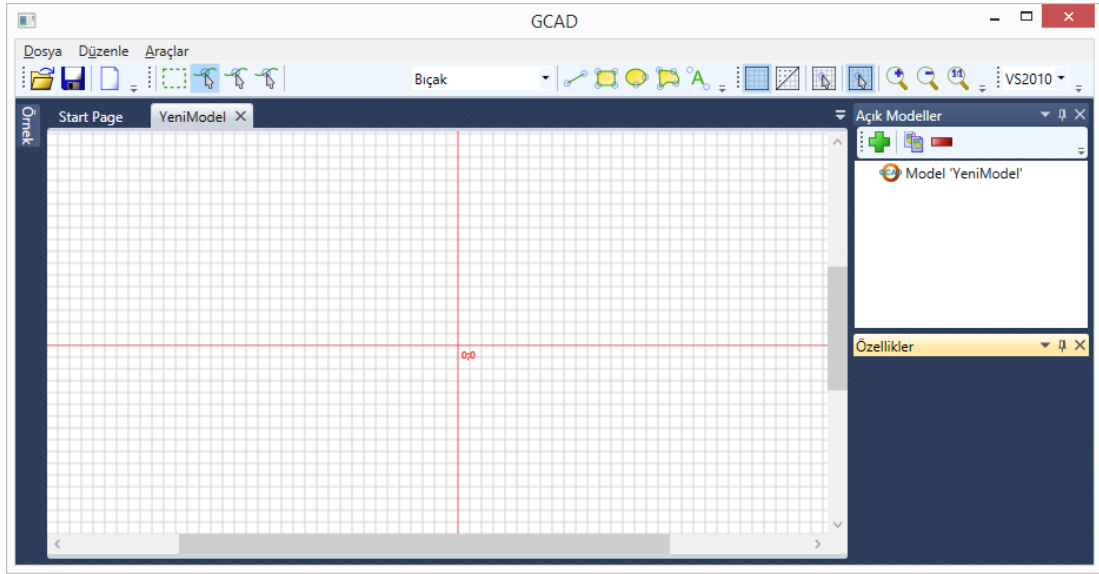


Figure 4.10 First view of GCAD after new project is created

#### 4.4.2.4 Select Area

Select Area button changes the design area mode to select mode. One or more shapes can be selected with this tool for multiple processes.

#### 4.4.2.5 Edit Shape

Edit shape button changes the design area mode to edit mode. In edit mode, users can add new line, rectangle, ellipse, curve and text to the design. Endpoints are selectable and modifiable in this mode. User can move control points and endpoints to another coordinates.

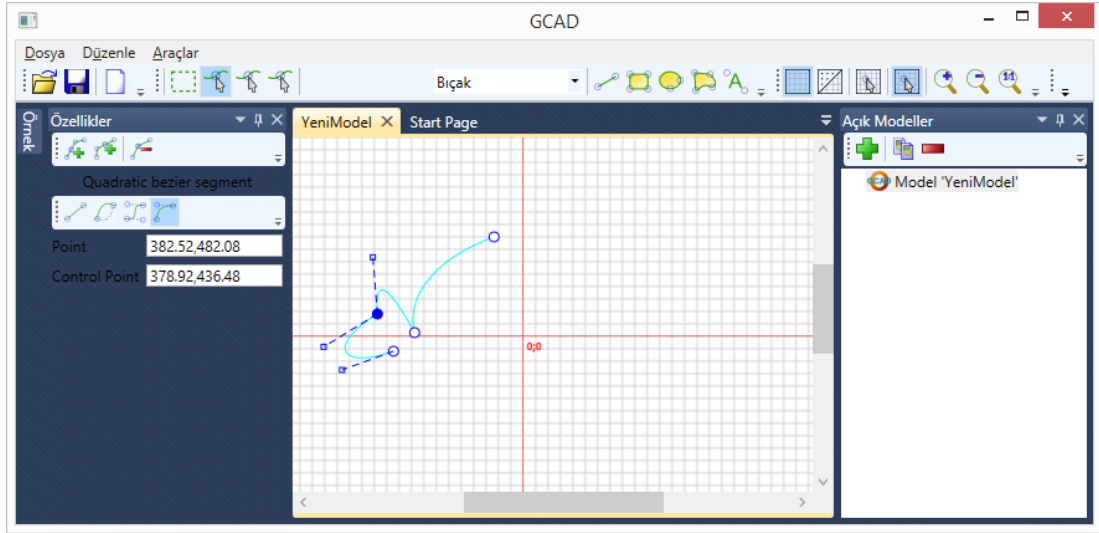


Figure 4.11 Edit mode of GCAD

#### 4.4.2.6 Scale Shape

Scale button changes the design area mode to scale mode. User can scale shapes in this mode. The rectangle with dashed lines shows border of the shape to scale. 4 visible and 1 invisible points are located in design area by application. 4 visible points are corner points such as Top Left, Top Right, Bottom Left, and Bottom Right. The last point that is invisible is located in center of 4 corner points. User moves a corner point for scale the shape. After user moves the point, horizontal and vertical scale ratio is calculated. Then equation 3.21 is used with horizontal and vertical scale ratio and the center point for scaling the shape.

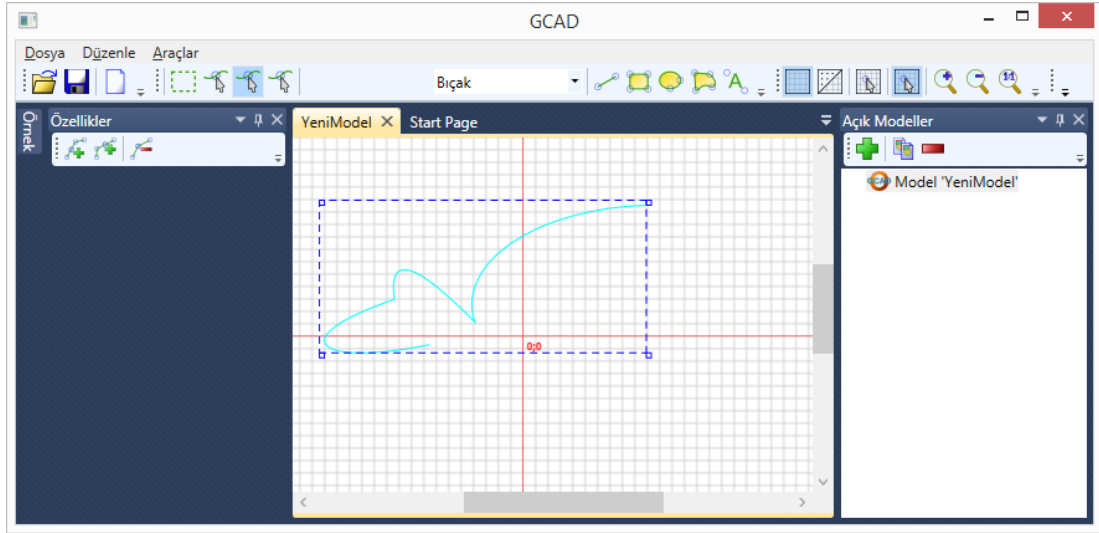


Figure 4.12 Scale mode of GCAD

#### 4.4.2.7 Rotate Shape

Rotate changes the design area mode to rotate mode. User can rotate shapes in this mode. The circle with dashed lines shows border of shape rotation. There is 1 point for rotation. The point is regarded as a center point. When a pen cursor appears, user can rotate the shape. With equation 3.26, rotation angle is calculated. Then equation 3.19 is used with rotation angle and the center point.

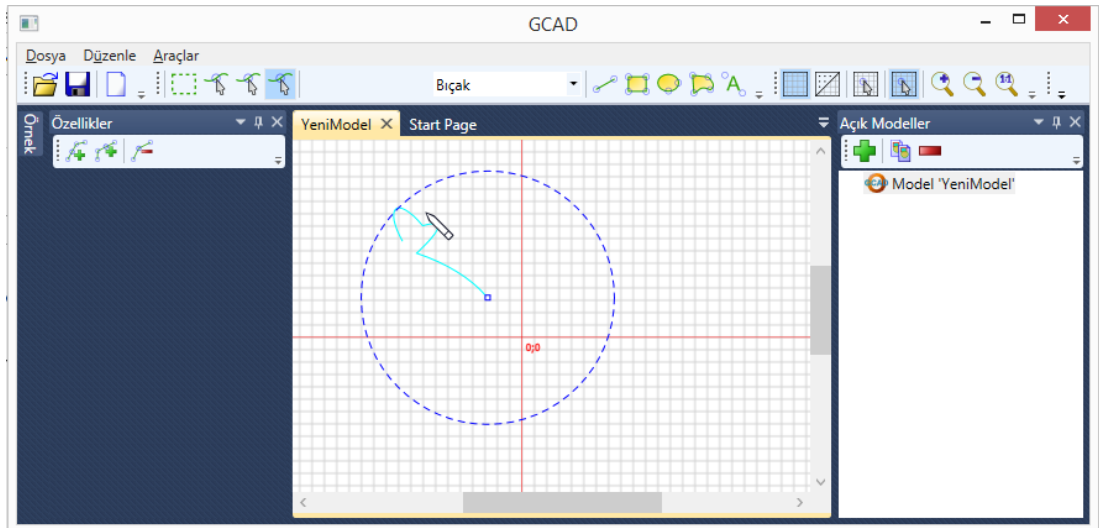


Figure 4.13 Rotate mode of GCAD

#### 4.4.2.8 Type of shape

Type of shape dropdownlist sets tool type will use in CNC machine for selected shape. User can choose a tool in some options. Cutter head of CNC machine runs according to the option. The options are;

- Knife
- Draw
- Zero punch
- 0.8mm punch
- 1.2mm punch

The knife cuts the material according to drawn part of design with knife tool. The draw tool makes just a draw on material. The machine points a punch with zero punch like draw, it does not punch. The machine punches with 0.8 mm and 0.12 mm punch tools.

#### 4.4.2.9 Line

Line button draws a line as. A line has two point and their coordinate's properties. They have start point and end point. Because a line can be defined with two point.

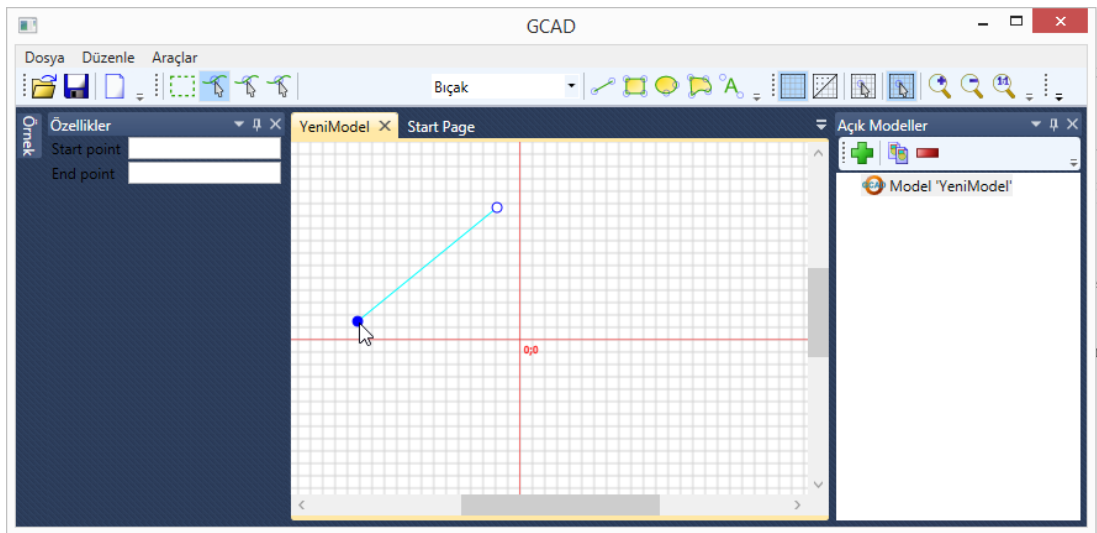


Figure 4.14 Line tool of GCAD

#### 4.4.2.10 Rectangle

Rectangle button draws a rectangle. A rectangle can be defined with 2 diagonal corner points. A rectangle has 4 properties such as width, height, x and y coordinates of selected corner point. Scaling a rectangle without lost characteristic that owner of four right angles is possible with only one control point.

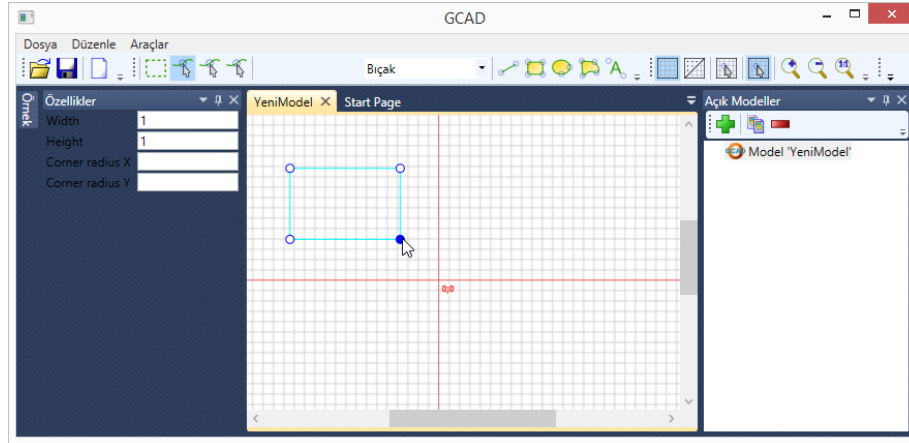


Figure 4.15 Rectangle tool of GCAD

#### 4.4.2.11 Ellipse

Ellipse button draws an ellipse or a circle. Ellipse has two axes that are called major and minor axis. Changing length of one of axis scales the ellipse. So scaling an ellipse is possible for two control points for width and height.

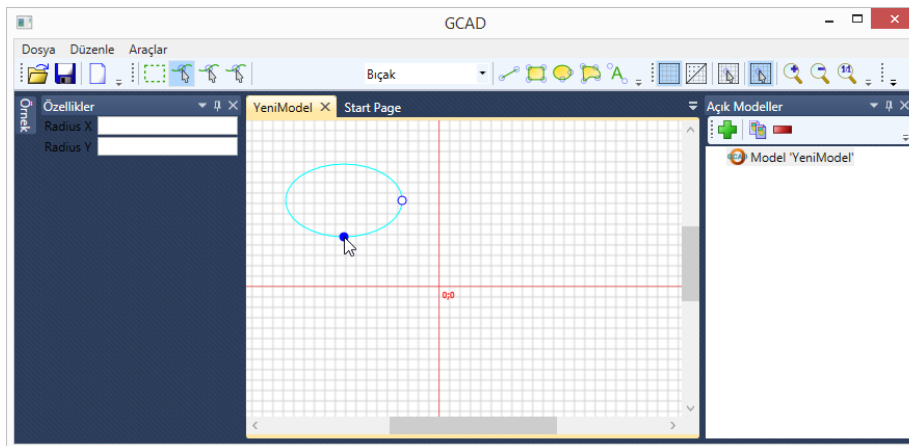


Figure 4.16 Ellipse tool of GCAD

#### 4.4.2.12 Curve

Curve button draws a chain of curves that may be different types. Those types can be a line, an elliptical arc, a quadratic bezier, or a cubic bezier. The button draws a line as a curve in default. Then user can switch type to another type. The curve includes a start point, endpoints and control points that are connected to an endpoint. Curve starts with a start point and end an endpoint. The curve chain is expanded with adding endpoints.

In following figure, the curve chain starts with a start point. A endpoint connected to the start point as line type. So the first part is a line. The second part is elliptical part, because of second endpoint connected to first endpoint as a elliptical arc type. Third endpoint is quadratic bezier type. Two controls points are connected to it. Actually quadratic beziers has one control points, third endpoint normally may have one control point. But the next endpoint is a cubic bezier type endpoint that has two control points. One of two controls first endpoint and another of two controls the second endpoint in cubic endpoints. Curves are examined in chapter 3.2.1 and illustrated in figure 3.14.

User can use properties pane for adding a endpoint before or after from selected endpoint, removing selected endpoint, changing curve type of selected endpoint, and editing own or control points' connected to the selected point coordinates.

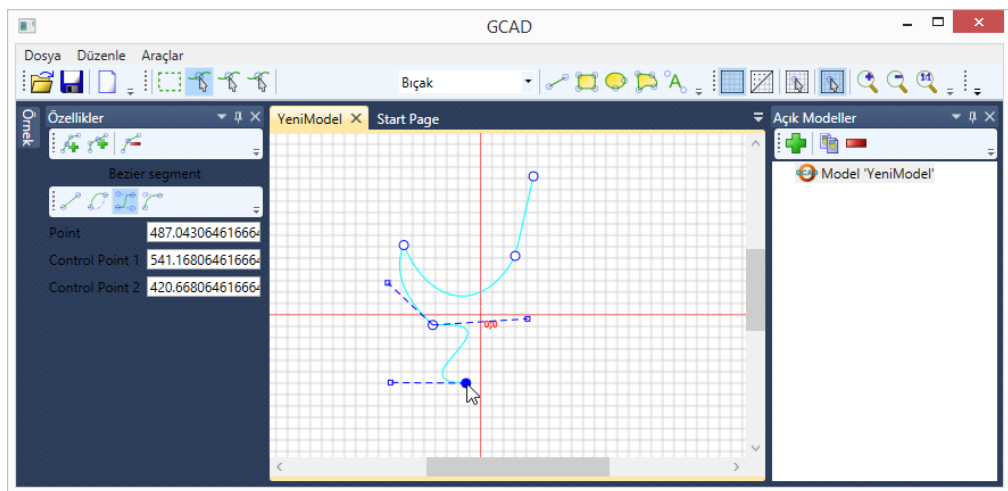


Figure 4.17 Curve tool of GCAD

#### 4.4.2.13 Text

Text button puts a text as information. This text fields can not be used in cutting process. Text field has properties such as context, font size, font family, alignment in own area, trimming option, bold, and italic.

#### 4.4.2.14 Change background of design area

Change background of design area zone makes possible to show/hide grid, to show/hide lines between dots on grid, to snap to grid, to show/hide axis in design area.

#### 4.4.2.15 Magnifying

Magnifying zone makes possible to zoom out, to zoom in, and zoom too 100% for designing in more detail.

#### 4.4.2.16 Theme

Theme dropdown list gives four option such as Generic, Aero, VS2010, and Metro to change application theme. Those themes are features of Extended WPF Toolkit's Avalondock component. Users can change theme by choosing one among four of them.

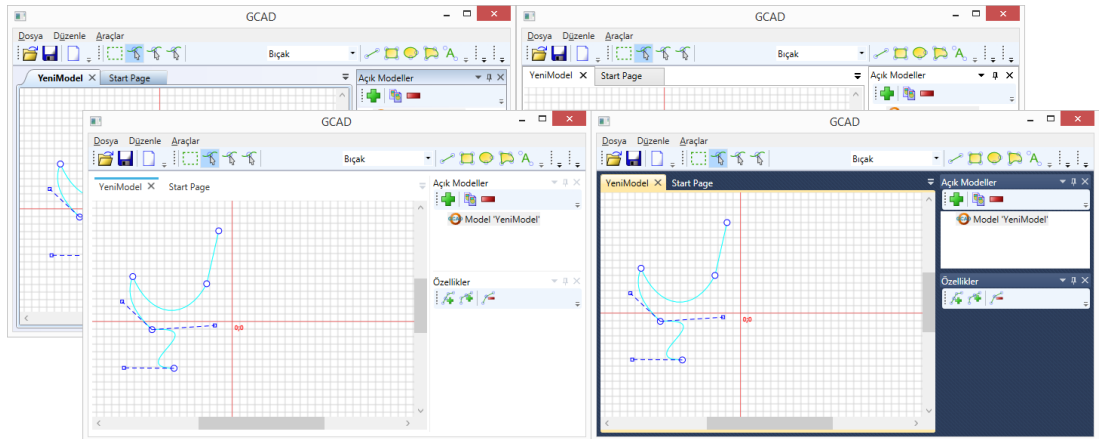


Figure 4.18 Avalondock themes in GCAD

## **CHAPTER FIVE**

### **CONCLUSIONS**

This thesis aims at designing the solution that includes converting manual patterns to vectorized patterns and integrate it with a CAD/CAM application which will be used in project supported cutting and planning process and makes possible to modify the design according to the cutting machine. It aims to replace manual drafting with an automated process.

The goal of the thesis is implementing an application that can import manual patterns as scanned image. By this way, the application can convert the image to a design as vector image, and can convert the design to machine programs with G-Code and ILDA standards of projection supported CNC.

In traditional method of leather cutting, wooden or cardboard patterns prepared for the model to be manufactured and a knife are used. This study is built for shoe designer and operators of cutting machines to facilitate importing and designing their patterns and using on cutting machines. This thesis benefits from recent and common image processing methods and techniques, and uses open source material as much as possible. Because, they are open to develop.

The application in this study is developed for CNC Routers which do 2D manufacturing. And it is called as GCAD. Users can design easily a pattern with this application. Because the application provides an option to importing manual and traditional patterns to design. So it eases the design process.

GCAD does not depend to a CNC machine, because of converting the design to G-Code standards for CNC machines and to ILDA standards for laser projections on the machines.

GCAD files and type which are used for saving and transferring the design are mostly and frequently used common standards such as well-formed XML, XAML, G-Code and ILDA. Those types can be easily modified and transferring between systems.

GCAD uses free licensed libraries as possible as. Because, editing, using and sharing the libraries are free in basic. If the library has a bug or needs an update, it can be fixed without waiting developers of the library.

Geometrical approximation and methods are used in all steps of application in this study. Bezier curves and other geometric types are modifiable, scalable, analyzable and cost less resources. They are open to develop for future features. The geometric types can be calculated with standard mathematical and geometrical methods and functions.

This thesis gives related works about CAD/CAM applications in Chapter 2. In Chapter 3 the methods of the solution in thesis are explained. GCAD software that is application of the solution was elaborated in Chapter 4.

In the future, the GCAD can be enhanced by adding some features to it. One of these features is helper tools such as mirroring, scaling used in shoe leather industry. Second one of it, is integration with common cad file formats such as DXF.

One of the other features which may be added is web and mobile capability. By using web or a mobile environment, designers can manipulate their design on location-independent. When they finish their design, they will send them to CNC machine operator or directly to CNC machine.

Another future feature is combining two patterns which are vector image. When the application imports two scanned pattern images, then it can combine as one pattern design.

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