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Computer Vision-Based 3-D Reconstruction for Object Replication

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Abstract

The Microsoft Kinect for Windows has proven to be a valuable tool in the field of computer vision. The Kinect is comprised of an infrared laser projector and depth sensor. The depth data of a scene is run through a bilateral filter and vector mathematics is used to define the coordinates, connecting lines, the vertices, and edges to form a three-dimensional mesh. The software displays the raw depth data and infrared camera image, this allows the user to filter out objects closer or further than a specified depth, and exports the reconstructed three-dimensional mesh. That mesh is then sliced into horizontal layers and converted into G-Code, a machine language that maneuvers the three-dimensional printer where to extrude the ABS plastic to create a physical replica of the reconstructed object.

Contents

1 Introduction

The Computer Vision-Based 3D Reconstruction for Object Replication is accomplished by using a Kinect for Windows. Originally, the Kinect was created for entertainment, but recently it has been introduced to the field of robotics and computer vision. The Kinect is a quick, reliable, and affordable tool that uses a near-infrared laser pattern projector and an IR camera, along with the sensor and software development kit, to calculate 3D measurements.

The 3D printer is another part of the robotics field that is beginning to find an increasing number of uses. The most innovative aspect of the 3D printer is the ability to print an object, regardless of interconnecting internal components, and have it function as intended. This means that any connecting gears that are printed with the 3D printer will in fact turn as they are supposed to.

2 Methods

2.1 Calibration

The Kinect can be calibrated in a way similar to other cameras for computer vision, the only difference is that changes in the depth have to be present with the pattern in order to calibrate the depth camera. The Kinect needs to take an image of a checkerboard pattern.

2.2 Stereo Reconstruction

Once the Kinect has been calibrated, all that is needed now for the stereo reconstruction is a triangulation of viewing rays.

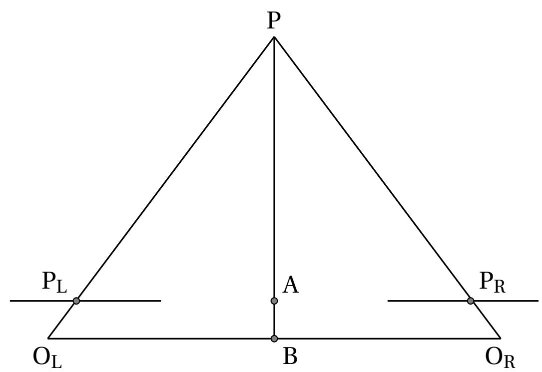


Figure 1: Visual Representation of Depth Disparity

P is the location of the object in the world, O_L and O_R are the left and right camera centers, P_R and P_L are the appearance of the point P in the two image planes where $P_L = \begin{bmatrix} x_L \\ y_L \end{bmatrix}$. The distance between O_L and O_R is T, or the distance between the left and right camera. The distance between A and B is the focal length of the cameras. If we define the distance between P and B as distance Z, the following equation can be used to represent the ratio between T and Z, using the theorem of like triangles: $\frac{T}{Z} = \frac{T+x_L-x_R}{Z-f} or \frac{T-x_R-x_L}{Z-f}$ Cross multiplying these equations results in: $\frac{Z(T-x_R-x_L)}{Z-f} = \frac{T(Z-f)}{Z}$ These calculations show that depth, or Z, is inversely proportional to disparity. This means that $P_L = \frac{f^L P}{Z_L}$. and $P_R = \frac{f^R P}{Z_R}$.

Once there is a corresponding point pair for P from the two images, an algorithm would undo the scale and shift of the pixel points in order to obtain the 2 dimensional camera coordinates. The midpoint algorithm is then used to find the real three-dimensional world coordinate that corresponds to that point pair.

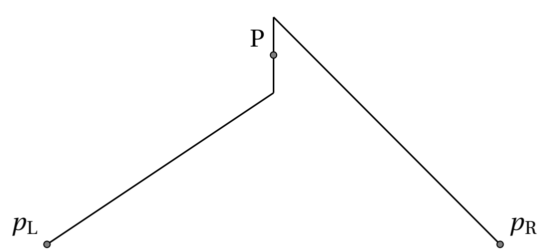


Figure 2: Visual Representation of the Midpoint Algorithm

Above are the rays $\overrightarrow{O_R p_R}$ and $\overrightarrow{O_L p_L}$ are drawn. The line connecting the two vectors, which is also perpendicular to both, is obtained by taking the cross product of these two vectors. The vector from p_L is equal to $a\vec{p}_L$, since point p_R is distance T away from p_L, the vector from p_R is equal to $b\,{}^{L}R_R\vec{p}_R + T$. The segment connecting these two vectors can be represented as $c\vec{p}_L x\,{}^{L}R_R\vec{p}_R$, where a, b and c are unknown constants that can be solved using the three equations explained above.

The point P lies on the center of this line and be found by ${}^{L}P = a\vec{p}_L + \frac{c}{2}\vec{p}_L x\,{}^{L}R_R\vec{p}_R$ In order to get the world point M, this point would just be divided by the Intrinsic and extrinsic matrices.

Figure 3: The Xbox Kinect, the sensor on the left is the infrared light source, the center is a RGB camera and the 3D depth camera is on the right. in addition to these cameras, the base has a motorized tilt and a multi-array mic goes along the bottom of the wand.

The Kinect accomplishes this triangulation by using the known information about the sensor, the data obtained from the infrared projection and the image received from the camera. The sensor will project invisible light onto an object, the light bounces back and the infrared sensor reads back the data. These clusters of light that are read back can be matched to the hard-coded images the Kinect has of the normal projected pattern and allows for a search for correlations, or the matching points. While looking through the camera's focal point, the point of interest will fall on a specific pixel, depending on how close or far away it is, this means that we know along which trajectory this point is from the camera. The relative line of trajectory from the projector and from the camera, along with the known information about the distance between the cameras on the Kinect sensor, are used in the above described triangulation process to find the three-dimensional coordinates of the point. Figure 3 shows how the three cameras are arranged on the Kinect.

2.3 Bilateral Filter

In order to make this data more manageable, a bilateral filter is used to remove the erroneous measurements. This filter will just take every point, and recalculate the value of that point based on the waited average of the surrounding pixels in a specified neighborhood. The process takes away some of the sharpness of the depth map, but it removes the noise that will skew the results of the three dimensional reconstruction. The filter takes every pixel in the image and replaces its value with $BF[I]_P = \frac{1}{16}\begin{pmatrix} 1 & 2 & 1 \\ 2 & 4 & 2 \\ 1 & 2 & 1 \end{pmatrix}$ times the neighborhood of the 3 by 3 square of pixels around the pixel that is being changed. This resulting pixel value represents the average of the 9 pixels, where the closer pixels weight in the average is heavier than the further pixel values.

2.4 Mesh Construction

Once the depth data has been filtered, it can be used to create a three-dimensional mesh of the object. At each pixel location two vectors are made, each connecting that three-dimensional point to the next point to the right and the next point below. Cross multiplying these two vectors results in the orientation vector for the point. As the loop goes through each point, it created a triangle in three-dimensional space out of the existing points and calculated orientations, which are recorded in three-dimensional point and vector collections. Each of these points must be added in the correct order, keeping with the right hand rule, so that each reconstructed triangle is oriented in the correct direction. While these three points and vectors are added, separate collections of the indices and texture informations are recorded.

While reconstructing the front face of the mesh, the code goes through every x and y pixel coordinate starting at (0,0) and ending with (230,640), incrementing by a set number. Down sampling, for testing, was accomplished by setting this number to two so that only every other point was processed. In the KinectScan software, the user can crop out the left, right, top or bottom of the image. Changing these sliders indicated where on the image the reconstruction of the mesh is going to begin and end. The user can also specify what they would like the minimum and maximum depth to be.

In order to filter out depth that is further than the intended value, the software looks at the square where the point of interest is the upper left corner. If all four points are outside of the depth range, that point is skipped. If any of the four points on that square are within the depth range, the square is constructed. For this square, any point that is not within the depth range is given the depth of the back wall, the value specified by the user. Lastly, the back wall of the three-dimensional reconstruction is built. A loop goes through every point that is already in the three-dimensional point collection, each point is copied to the end of the collection with the depth changed to the depth of the back wall. The same number of orientation vectors are added to the collection of three-dimensional vectors, each one equaling [0,0,-1]. [1]

2.5 G-code Conversion

The RepRap firmware uses G-code to communicate to the 3D printer, specifically to define the print head movements. This code has commands that tell the print head to move to a certain point with rapid or controlled movement, turn on a cooling fan, or selecting a different tool. Since this 3D printer does not have as many features, the G-code generator does not have to add much complicated code, but rather just instructions to the printer head. Since the printer continuously dispenses plastic, it is necessary to find a path for it to take that will build up the reconstructed object layer by layer without placing too much plastic in any specific area. This requires cutting up the reconstructed object into layers and then finding the best path to traverse that layer without overlapping any part of that path. The G-code converter takes in the STL file, cuts it up into horizontal layers and then calculates the about of material that is needed to fill each slice.

3 Experimental Results

Figure 4: The Kinect raw depth field, with the RGB image mapped to it, without bilateral filter

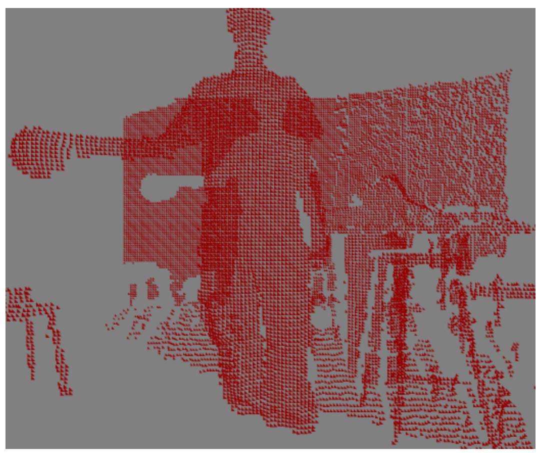


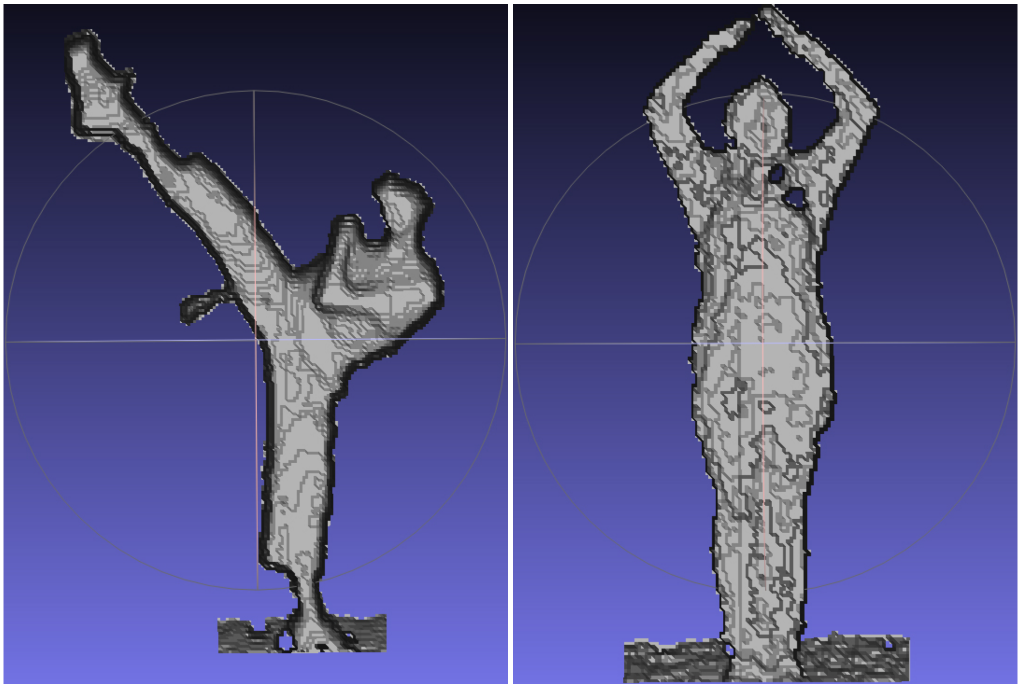
Figure 5: Triangles representing the 3D data

Figure 6: The 3D data with the correct background filtered out

Figure 7: Comparison of the raw depth data and the Triangles that represent the 3D data

4 Discussion

Part of the issue of working with this 3D printer was that many of the parts used in the construction of the machine were actually printed by another 3D printer. This meant that before we could start the construction of the printer, we had to wait on all of the correct parts to be printed. Even once we thought that we had all of the required pieces, we found two important parts that we were missing that we have to go to the Rutgers Maker Space to get printed. We also found that many of the plastic parts were made to be the exact size of the rods that needed to be placed into them, this meant that it took a lot of force to get some of the components to fit together properly. At one point we tried to use hot water to make the printed plastic more malleable but we fear that this made some of the pieces warp.



(a) Actual Robot (b) SolidWorks CAD Render

Figure 8: Comparison between Gaussian filter (left) and non-filtered (right) applied to the depth data

Another big issues that was found with he construction of the 3D printer was the lack of good document ion on assembly. For the triangular base structure had to be taken apart and reassembles multiple time sin order to fix errors. One example was the motor bracket for the motor that controls the movement along the y-axis, there was not good diagrams to show which side of the machine this part should be placed and what direction it should be oriented. Figure 9 shows a number of the unlabeled parts that we received from IEEE. Since documentation as hard to find and none of the parts were labeled, we also had trouble finding the correct STL files to send in in order to get ore parts. We knew that we were missing the brackets that connect the two top motors to the threaded rod that controls the movement along the z-axis, but we did not know what file needed to be printed.

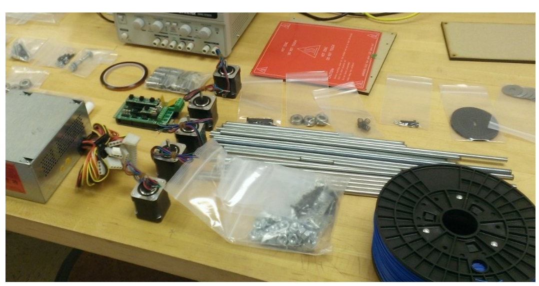


Figure 9: Parts of the 3D Printer

Even once the mechanical parts of the 3D printer have been constructed, we still need to calibrate all of the axes, add all of the electrical components, calibrate the firmware and build the protective frame around the printer. Figure 10 shows the constructed frame, x,y and z-axes and the installed printed. One of the issues that we will run into as we complete the 3D printer is the extruder. This component is responsible for heating and melting the ABS plastic and placing it onto the right place on the heat bed. We have discovered a problem that normal solder cannot handle the heat that is needed to melt the ABS plastic and the piece falls apart as the machine heats up. In order to fix this issue, we need to order silver solder that will be capable of withstanding a temperature of 221 degrees Fahrenheit.

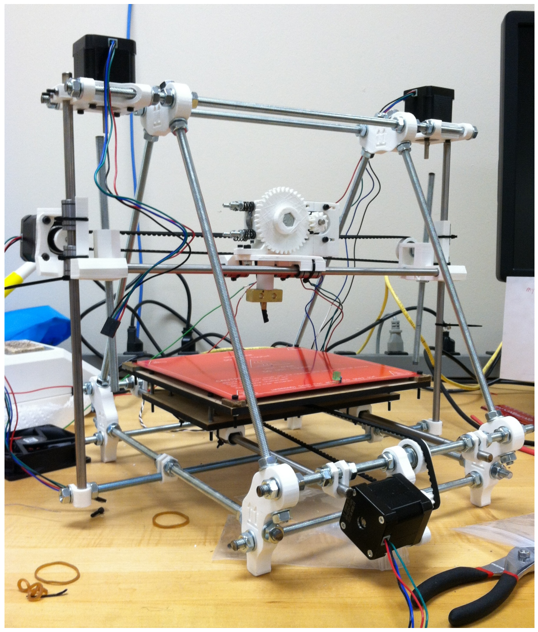


Figure 10: Construction of the 3D Printer Frame and x,y and z-axes

The biggest issue that we have had with the software component of this project was the lack of examples. Other people who have worked on similar projects had been using the original version of the Microsoft Kinect Software Development Kit. This means that a many implementations used packages that are no longer part of the SDK that we have to work with. We've had to find ways to make the new SDK, which was released in 2012, work in a way similar to the old SDK.

5 Cost Analysis

Item	**Description**	**Cost**
RepRap Prusa Mendel Iteration 2	Open Hardware based 3-D Printer	$ 725.00
Microsoft Kinect for Xbox	Video camera and depth sensor	$ 98.79
Acrylic casing, small tools, glue, misc..	Parts for creating the case	$ 59.65
Kinect Power Supply Cable	External power source for Kinect	$ 6.70
	Total Cost:	**$ 890.14**

Table 1: Overview of hardware and cost for project.

6 Current Trends in Robotics and Computer Vision

6.1 Kinect Revolution

One of the reasons that the Kinect has become so popular for computer vision projects is that it is a cheap, quick, and highly reliable for 3D measurements. Many researchers are beginning to look into the possibility of using this device to achieve everything from a 3D reconstruction of a scene to aiding in a SLAM algorithm. The fact that this device is so affordable, and so many new resources are available, makes the Kinect a viable device for conducting research in the field of robotics and computer vision.

The KinectFusion Project is slightly different than other projects that were using the Kinect; instead of using both the RGB cameras and the sensor, this project tracks the 3D sensor pose and preforms a reconstruction in real time using exclusively the depth data. This paper points out that depth cameras aren't exactly new, but the Kinect is a low-cost, real-time, depth camera that is much more accessible. The accuracy of the Kinect is called into questions, the point cloud that the depth data creates does usually contain noise and sometimes has holes where no readings were obtained. This project also considered the Kinect's low X/Y resolution and depth accuracy and fixes the quality of the images using depth super resolution. KinectFusion also looks into using multiple Kinects to preform a 3D body scan; this raises more issues because the quality of the overlapping sections of the images is compromised.

Another KinectFusion Project is the Real-time 3D Reconstruction and Interaction, this project is impressive because the entire process is done using a moving depth camera. With this software, the user can hold a Kinect camera up to a scene, and a 3D construction would be made. Not only would the user be able to see the 3D Reconstruction, but they would be able to interact with it; for instance, if they were to throw a handful of spheres onto the scene, they would land on the top of appropriate surfaces, and fall under appropriate objects following the rules of physics. To accomplish this, the depth camera is used to track the 3D pose and the sensor is used to reconstruct the scene. Different views of the scene are taken and fussed together into a singe representation, the pipe line segments the objects in the scene and uses them to create a global surface based reconstruction. This project shows the real-time capabilities of then Kinect and why that makes it an innovative tool for computer vision

A study shown in the Asia Simulation Conference in 2011 demonstrated that a calibrated Kinect can be combined with Structure from Motion to find the 3D data of a scene and reconstruct the surface by Multi-view Stereo. This study proved that the Kinect was more accurate for this procedure than a SwissRanger SR-4000 3D-TOF camera and close to a medium resolution SLR Stereo rigs. The Kinect works by using a near-infrared laser pattern projector and an IR camera as a stereo pair to triangulate points in 3D space, then the RGB camera is used to reconstruct the correct texture to the 3D points. This RGB camera, which outputs medium quality images, can also be used for recognition. One issue this study found was that the resulting IR and Depth images were shifted. To figure out what the shift was, the Kinect recorded pictures of a circle from different distances. The shift was found to be around 4 pixels in the u direction and three pixels in the v direction. Even after the camera has been fully calibrated, there are a few remaining residual errors in the close range 3D measurements. An easy fix for this error was to we form a z-correction image of z values constructed as the pixel-wise mean of all residual images and then subtract that correction image from the z coordinates of the 3D image.[2] Though the SLR Stereo was the most accurate, the error e (or the Euclidean distance between the points returned by the sensors and points reconstructed in the process of calibration) of the SR-400 was much higher than the Kinect and the SLR. This study shows that the Kinect is possible cheaper and simpler alternative to previously used cameras and rigs in the computer vision field.

Another subject of research that is looking into using the Kinect is the simultaneous localization and mapping algorithm, used to create a 3D map of the world so that the robot can avoid collision with obstacles or walls. The

SLAM problem could be solved using GPS if the robot is outside, but inside one needs to use wheel or visual odometry. Visual odometry determines the position and the orientation of the robot using the associated camera images, algorithms like Scale Invariant Feature Transformation (SIFT), used to find the interest points, and laser sensors, used to collect depth data. Since the Kinect has both the RGB camera and a laser sensor, this piece of technology is a good piece of hardware to use for robots computing the SLAM Algorithm. In the study conducted by the students in the Graduates School of Science and Technology, at Meiji University, they found that the Kinect worked well for this process for horizontal and straight movement, but they had errors when they tried to recreate an earlier experiment, this means that their algorithm successfully solves the initial problem, but accuracy fell over time.[5] They found that the issue was not with the Kinect, and that it could be solved using the Speed-Up Robust Feature algorithm (SURF) and Smirnov-Grubbs test to further improve the accuracy of their SLAM Algorithm. This study proved that the Kinect was a reasonable, inexpensive and non-special piece of equipment that is capable of preforming well in computer vision applications.

It seems as though the Kinect is a popular choice in current robotics and computer vision. This device is affordable, easily obtainable, and capable of a lot more than is expected from a video game add on. The Kinect combines a near-infrared laser pattern projector and an IR camera in one tool, and when combined with this eliminates the set up of some other configuration. The Kinect is also surprisingly accurate, requiring only some optimization software to make the results comparable to the results from a medium resolution SLR Stereo rig.

6.2 3-D Printing Future

One of the most innovated uses for the 3D Printer is its applications in the medical field. Since 2010, people have been using 3D printers to print out prosthetic limbs. One company in California has been printing the totally customizable prosthetics, which cost about one tenth of traditional prothetic limbs. Another company is looking at the possibility of using a 3D printer to print a house. Right now the design fits on the back of a tractor trailer and the 3D printer prints out custom concrete parts the are then assembled to complete the house. Some 3D printers have the ability to change the printing head, so it can begin printing with one material and then switch to a different material, all based on the code it receives, this means that a 3D printer could theoretically print the concrete part of the house and switch to printing the plastic siding or the glass windows all on the same path around the outside of the house. The most importunes aspect of these 3D printer applications is that it drastically cuts down on production costs, allowing the consumer to pay a lower price and get a completely customized product. Rather than paying a person to design the object, and then have a bother construct it, with a 3D printer all that needs to be done is the design and the 3D printer automates the entire construction process. For example, the 3D printed prosthetics cost 5,000 dollars to print and customize by covering the 3D printed material in a shoe or sleeve while a normal generic prothetic would cost about 60,000 dollars.[6] The 3D printer is a piece of technology that could continue to make the price of consumer goods fall and allow for more customization than has ever existed for consumer products.

In recent news, biomedical scientists have taken the 3D printing technology a step further than prosthetics. A man had 75% of his skull replaced but a 3D printed implant made by Oxford Performance Materials. Plastics have been used since the 1940's to replace missing bone fragments, and 3D modeling techniques have been used to match the size and shape of the plastic to someones skull. This Connecticut based company combined the 3D modeling techniques with 3D printing technology to produce the replacement part that only took five days to fabricate.[**?**] The material that it is printed with has some of the same properties as bones and are osteoconductive, so the skull will actually grow and attach itself to the implant. This is also much better than metals that would block doctors from seeing past the implant in X-rays. This company is now also looking at using this procedure to 3D print other replacement bones for victims or cancerous bone or trauma.

Even though lower cost of production is a goal for many industries, the 3D printing technology can be considered a disruptive technology, meaning that over the course of a short period of time it could change an existing market and value network while replacing existing technology. An article in the Harvard Business Review explains that good would be produced at or close to their point of purchase or consumption. Even if this is not the case with every industry, the cost will be offset by the elimination of shipping the completed object to the consumer, something like car parts could be printed in a metropolitan area rather than made and shipped from a factory. This article also mentions how the 3D printer would allow for cheap and efficient customization of these products. Since changing the shape, color or material of what you want to print is only a mater of changing code, the first model could be relatively different than the second model for virtually no extra cost. [3] The 3D printer could potentially affect the global market. Many products are manufactured overseas since it is much cheaper for the pieces to be created an assembled by underpaid workers, when 3D printing is perfected the parts could be made and assembled by a machine in the US for less than it cost to have the product manufactured and shipped from overseas.

An article in Machine Design talks about what changes are being made to the 3D printers in order to make them more durable, user friendly and affordable. One brand, LeapFrog, has made the entire device out of aluminum and replaced the stepper-motor drivers with professional drivers that last longer. This company has also added a duel option extruder so that the printer could construct something like a bridge by adding the plastic from one extruder and a water soluble support system with the other extrude that can be washed away once the printing is finished. This printer also uses PLA plastic, which is more brittle and has a lower melting temperature, can print smoother edges than the usual ABS plastic. Another brand, FormLabs, uses a liquid photopolymer instead of a spool of plastic, this resin cuts the price of printing materials in half and allows for a layer thickness of only 25 microns. The RepRap 3D printer has been designated a self-replicating printer because it can be used to print parts for constructing another 3D printer. It is believed that between 20,000 and 30,000 of these machines are now in existence.[4] The company Staples has started "Staples Easy 3D" in Belgium and the Netherlands, where anyone can upload their file to the center and later pick up the 3Dc model at their local staples or have it shipped to their house. Services like this are a sign that 3D printing will soon be as mainstream as 2D printing.

7 Appendix

0.1 KinectScan Application Code

```
ï»¿namespace kinectScan
{
    using System;
    using System.ComponentModel;
    using System.Globalization;
    using System.IO;
    using System.Threading.Tasks;
    using System.Drawing;
    using System.Diagnostics;
    using System.Windows;
    using System.Windows.Controls;
    using System.Windows.Media;
    using System.Windows.Media.Imaging;
```

```
using System.Windows.Media.Media3D;
using System.Windows.Threading;

using HelixToolkit.Wpf;

using Microsoft.Kinect;
using Microsoft.Kinect.Toolkit;

/// <summary>
/// Interaction logic for MainWindow.xaml
/// </summary>
public partial class MainWindow : Window
{

    /// <summary>
    /// Timestamp of last depth frame in milliseconds
    /// </summary>
    private long lastFrameTimestamp = 0;

    /// <summary>
    /// Timer to count FPS
    /// </summary>
    private DispatcherTimer fpsTimer;

    /// <summary>
    /// Timer stamp of last computation of FPS
    /// </summary>
    private DateTime lastFPSTimestamp;

    /// <summary>
    /// Event interval for FPS timer
    /// </summary>
    private const int FpsInterval = 5;

    /// <summary>
    /// The counter for frames that have been processed
    /// </summary>
    private int processedFrameCount = 0;

    /// <summary>
    /// Active Kinect sensor
    /// </summary>
    private KinectSensor sensor;
```

```
        /// <summary>
        /// Kinect sensor chooser object
        /// </summary>
        private KinectSensorChooser sensorChooser;

        /// <summary>
        /// Format of depth image to use
        /// </summary>
        private const DepthImageFormat dFormat = DepthImageFormat.Resolution320x240Fps30;

        /// <summary>
        /// Format of color image to use
        /// </summary>
        private const ColorImageFormat cFormat = ColorImageFormat.
            InfraredResolution640x480Fps30;

        // stores furthest depth in the scene
        public ushort greatestDepth = 0;

        // array for all of the depth data
        private int[] Depth = new int[320 * 240];

        // stores all of the 3D trianlges with normals and points
        Model3DGroup modelGroup = new Model3DGroup();

        // material placed over the mesh for viewing
        public GeometryModel3D msheet = new GeometryModel3D();

        // collection of corners for the triangles
        public Point3DCollection corners = new Point3DCollection();

        // collection of all the triangles
        public Int32Collection Triangles = new Int32Collection();


        public MeshGeometry3D tmesh = new MeshGeometry3D();

        // collection of all the cross product normals
        public Vector3DCollection Normals = new Vector3DCollection();

        // add texture to the mesh
        public PointCollection myTextureCoordinatesCollection = new PointCollection();
```

```
        // storage for camera, scene, etc...
        public ModelVisual3D modelsVisual = new ModelVisual3D();


        public Viewport3D myViewport = new Viewport3D();

        // test variable
        public int samplespot;

        // variable for changing the quality 1 is the best 16 contains almost no data
        public int s = 1;

        // depth point collection
        public int[] depths_array = new int[4];

        // collection of points
        Point3D[] points_array = new Point3D[4];

        // collection of vectors
        Vector3D[] vectors_array = new Vector3D[5];

        //used for displaying RGB camera
        public byte[] colorPixels;
        public WriteableBitmap colorBitmap;

        public MainWindow()
        {
            InitializeComponent();
        }

        private void WindowLoaded(object sender, RoutedEventArgs e)
        {
            // Start Kinect sensor chooser
            this.sensorChooser = new KinectSensorChooser();
            this.sensorChooserUI.KinectSensorChooser = this.sensorChooser;
            this.sensorChooser.KinectChanged += this.OnKinectSensorChanged;
            this.sensorChooser.Start();

            // Start fps timer
            this.fpsTimer = new DispatcherTimer(DispatcherPriority.Send);
            this.fpsTimer.Interval = new TimeSpan(0, 0, FpsInterval);
            this.fpsTimer.Tick += this.FpsTimerTick;
```

```
            this.fpsTimer.Start();

            // Set last fps timestamp as now
            this.lastFPSTimestamp = DateTime.Now;
        }

        /// <summary>
        /// Execute shutdown tasks
        /// </summary>
        /// <param name="sender">object sending the event</param>
        /// <param name="e">event arguments</param>
        private void WindowClosing(object sender, System.ComponentModel.CancelEventArgs e
            )
        {
            // Stop timer
            if (null != this.fpsTimer)
            {
                this.fpsTimer.Stop();
                this.fpsTimer.Tick -= this.FpsTimerTick;
            }

            // Unregister Kinect sensor chooser event
            if (null != this.sensorChooser)
            {
                this.sensorChooser.KinectChanged -= this.OnKinectSensorChanged;
            }

            // Stop sensor
            if (null != this.sensor)
            {
                this.sensor.Stop();
                this.sensor.DepthFrameReady -= this.SensorDepthFrameReady;
                this.sensor.ColorFrameReady -= this.SensorColorFrameReady;
            }

            // Empty the canvas
            this.ClearMesh();
        }

        /// <summary>
        /// Handles adding a new kinect
        /// </summary>
        /// <param name="sender">object sending the event</param>
```

```
/// <param name="e">event arguments for the newly connected Kinect</param>
private void OnKinectSensorChanged(object sender, KinectChangedEventArgs e)
{
    // Check new sensor's status
    if (this.sensor != e.NewSensor)
    {
        // Stop old sensor
        if (null != this.sensor)
        {
            this.sensor.Stop();
            this.sensor.DepthFrameReady -= this.SensorDepthFrameReady;
            this.sensor.ColorFrameReady -= this.SensorColorFrameReady;
        }

        this.sensor = null;

        if (null != e.NewSensor && KinectStatus.Connected == e.NewSensor.Status)
        {
            // Start new sensor
            this.sensor = e.NewSensor;
            this.StartCameraStream(dFormat, cFormat);
        }
    }

    if (null == this.sensor)
    {
        // if no kinect clear the text on screen
        this.statusBarText.Content = Properties.Resources.NoKinectReady;
        this.IR_Title.Content = "";
        this.Model_Title.Content = "";
        this.RGB_Title.Content = "";
    }
}

/// <summary>
/// Handler for FPS timer tick
/// </summary>
/// <param name="sender">Object sending the event</param>
/// <param name="e">Event arguments</param>
private void FpsTimerTick(object sender, EventArgs e)
{

    if (null == this.sensor)
```

```
            {
                // Show "No ready Kinect found!" on status bar
                this.KinectStatusText.Content = Properties.Resources.NoReadyKinect;
            }
            else
            {
                // Calculate time span from last calculation of FPS
                double intervalSeconds = (DateTime.Now - this.lastFPSTimestamp).
                   TotalSeconds;

                // Calculate and show fps on status bar
                this.KinectStatusText.Content = string.Format(
                    System.Globalization.CultureInfo.InvariantCulture,
                    Properties.Resources.Fps,
                    (double)this.processedFrameCount / intervalSeconds);
            }

            // Reset frame counter
            this.processedFrameCount = 0;
            this.lastFPSTimestamp = DateTime.Now;
        }

        /// <summary>
        /// Reset FPS timer and counter
        /// </summary>
        private void ResetFps()
        {
            // Restart fps timer
            if (null != this.fpsTimer)
            {
                this.fpsTimer.Stop();
                this.fpsTimer.Start();
            }

            // Reset frame counter
            this.processedFrameCount = 0;
            this.lastFPSTimestamp = DateTime.Now;
        }

        /// <summary>
        /// Start depth stream at specific resolution
        /// </summary>
        /// <param name="format">The resolution of image in depth stream</param>
```

```
        private void StartCameraStream(DepthImageFormat dFormat, ColorImageFormat cFormat
            )
        {
            try
            {
                // Enable streams, register event handler and start
                this.sensor.DepthStream.Enable(dFormat);
                this.sensor.DepthFrameReady += this.SensorDepthFrameReady;
                this.sensor.ColorStream.Enable(cFormat);
                this.sensor.ColorFrameReady += this.SensorColorFrameReady;
                this.sensor.Start();
            }
            catch (IOException ex)
            {
                // Device is in use
                this.sensor = null;
                this.ShowStatusMessage(ex.Message);

                return;
            }
            catch (InvalidOperationException ex)
            {
                // Device is not valid, not supported or hardware feature unavailable
                this.sensor = null;
                this.ShowStatusMessage(ex.Message);

                return;
            }

            // Allocate space to put the pixels we'll receive
            this.colorPixels = new byte[this.sensor.ColorStream.FramePixelDataLength];

            //// This is the bitmap we'll display on-screen
            this.colorBitmap = new WriteableBitmap(this.sensor.ColorStream.FrameWidth,
                this.sensor.ColorStream.FrameHeight, 96.0, 96.0, PixelFormats.Gray16, null
                );
        }

        /// <summary>
        /// Event handler for Kinect sensor's ColorFrameReady event
        /// </summary>
        /// <param name="sender">object sending the event</param>
        /// <param name="e">event arguments</param>
```

```
        void SensorColorFrameReady(object sender, ColorImageFrameReadyEventArgs e)
        {
            using (ColorImageFrame colorFrame = e.OpenColorImageFrame())
            {
                if (colorFrame != null)
                {
                    // Copy the pixel data from the image to a temporary array
                    colorFrame.CopyPixelDataTo(this.colorPixels);

                    // Write the pixel data into our bitmap
                    this.colorBitmap.WritePixels(
                        new Int32Rect(0, 0, this.colorBitmap.PixelWidth, this.colorBitmap
                            .PixelHeight),
                        this.colorPixels,
                        this.colorBitmap.PixelWidth * colorFrame.BytesPerPixel,
                        0);
                }

                // set the RGB image to the RGB camera
                this.KinectRGBView.Source = this.colorBitmap;

            }
        }

        /// <summary>
        /// Event handler for Kinect sensor's DepthFrameReady event
        /// Take in depth data
        /// </summary>
        /// <param name="sender">object sending the event</param>
        /// <param name="e">event arguments</param>
        void SensorDepthFrameReady(object sender, DepthImageFrameReadyEventArgs e)
        {

            DepthImageFrame imageFrame = e.OpenDepthImageFrame();
            if (imageFrame != null)
            {
                double maxDepth = Far_Filter_Slider.Value;
                short[] pixelData = new short[imageFrame.PixelDataLength];
                imageFrame.CopyPixelDataTo(pixelData);
                this.greatestDepth = 0;
                for (int y = 0; y < 240; y++)
                {
                    for (int x = 0; x < 320; x++)
```

```
                {
                    // scale depth down
                    this.Depth[x + (y * 320)] = ((ushort)pixelData[x + y * 320]) /
                       100;

                    // finds the furthest depth from all the depth pixels
                    if ((this.Depth[x + y * 320] > this.greatestDepth) && (this.Depth
                       [x + y * 320] < maxDepth))
                    {
                        this.greatestDepth = (ushort)this.Depth[x + y * 320];
                    }


                }
            }
            // Blur Filter -- Guassian
            if (Filter_Blur.IsChecked == true)
            {
                for (int i = 641; i < this.Depth.Length - 641; ++i)
                {

                    short depthaverage = (Int16)((this.Depth[i - 641] + (2 * this.
                       Depth[i - 640]) + this.Depth[i - 639] +
                                              (2 * this.Depth[i - 1]) + (4 * this.
                                                 Depth[i]) + (2 * this.Depth[i +
                                                 2]) +
                                              this.Depth[i + 639] + (2 * this.
                                                 Depth[i + 640]) + this.Depth[i +
                                                 641]) / 16);

                    this.Depth[i] = depthaverage;
                    if ((this.Depth[i] > this.greatestDepth) && (this.Depth[i] <
                       maxDepth))
                    {
                        this.greatestDepth = (ushort)this.Depth[i];
                    }
                }
            }

            // Set the depth image to the Depth sensor view
            this.KinectDepthView.Source = DepthToBitmapSource(imageFrame);
        }
    }
```

```
        /// <summary>
        /// Flag check for a point within the bounding box
        /// </summary>
        /// <param name="x">location on the x plane</param>
        /// <param name="y">location on the y plane</param>
        private bool PointinRange(int x, int y)
        {
            double minDepth = Near_Filter_Slider.Value;
            double maxDepth = Far_Filter_Slider.Value;
            return ((this.Depth[x + (y * 320)] >= minDepth && this.Depth[x + (y * 320)]
                <= maxDepth) ||
                (this.Depth[(x + s) + (y * 320)] >= minDepth && this.Depth[(x + s) + (y *
                    320)] <= maxDepth) ||
                (this.Depth[x + ((y + s) * 320)] >= minDepth && this.Depth[x + ((y + s) *
                    320)] <= maxDepth) ||
                (this.Depth[(x + s) + ((y + s) * 320)] >= minDepth && this.Depth[(x + s)
                    + ((y + s) * 320)] <= maxDepth));

        }

        /// <summary>
        /// Create the mesh
        /// </summary>
        void BuildMesh()
        {
            double maxDepth = Far_Filter_Slider.Value;
            int i = 0;
            for (int y = (int)Top_Slider.Value; y < ((int)Bot_Slider.Value - s); y = y +
                s)
            {
                for (int x = (int)Left_Slider.Value; x < ((int)Right_Slider.Value - s); x
                    = x + s)
                {
                    //Any point less than max
                    if (PointinRange(x, y))
                    {
                        if (this.Depth[x + ((y + s) * 320)] >= maxDepth)
                        {
                            depths_array[0] = -this.greatestDepth;
                        }
                        else
```

```
            {
                depths_array[0] = -this.Depth[x + ((y + s) * 320)];
            }

            if (this.Depth[x + (y * 320)] >= maxDepth)
            {
                depths_array[1] = -this.greatestDepth;
            }
            else
            {
                depths_array[1] = -this.Depth[x + (y * 320)];
            }

            if (this.Depth[(x + s) + (y * 320)] >= maxDepth)
            {
                depths_array[2] = -this.greatestDepth;
            }
            else
            {
                depths_array[2] = -this.Depth[(x + s) + (y * 320)];
            }

            if (this.Depth[(x + s) + ((y + s) * 320)] >= maxDepth)
            {
                depths_array[3] = -this.greatestDepth;
            }
            else
            {
                depths_array[3] = -this.Depth[(x + s) + ((y + s) * 320)];
            }

            // triangle point locations
            points_array[0] = new Point3D(x, (y + s), depths_array[0]);
            points_array[1] = new Point3D(x, y, depths_array[1]);
            points_array[2] = new Point3D((x + s), y, depths_array[2]);
            points_array[3] = new Point3D((x + s), (y + s), depths_array[3]);

            // create vectors of size difference between points
            vectors_array[0] = new Vector3D(points_array[1].X - points_array
                [0].X, points_array[1].Y - points_array[0].Y, points_array[1].
                Z - points_array[0].Z);
            vectors_array[1] = new Vector3D(points_array[1].X - points_array
                [2].X, points_array[1].Y - points_array[2].Y, points_array[1].
```

```
                Z - points_array[2].Z);
            vectors_array[2] = new Vector3D(points_array[2].X - points_array
                [0].X, points_array[2].Y - points_array[0].Y, points_array[2].
                Z - points_array[0].Z);
            vectors_array[3] = new Vector3D(points_array[3].X - points_array
                [0].X, points_array[3].Y - points_array[0].Y, points_array[3].
                Z - points_array[0].Z);
            vectors_array[4] = new Vector3D(points_array[2].X - points_array
                [3].X, points_array[2].Y - points_array[3].Y, points_array[2].
                Z - points_array[3].Z);

            // add the corners to the 2 triangles to form a square
            corners.Add(points_array[0]);
            corners.Add(points_array[1]);
            corners.Add(points_array[2]);
            corners.Add(points_array[2]);
            corners.Add(points_array[3]);
            corners.Add(points_array[0]);

            // add triangles to the collection
            Triangles.Add(i);
            Triangles.Add(i + 1);
            Triangles.Add(i + 2);
            Triangles.Add(i + 3);
            Triangles.Add(i + 4);
            Triangles.Add(i + 5);

            // find the normals of the triangles by taking the cross product
            Normals.Add(Vector3D.CrossProduct(vectors_array[0], vectors_array
                [2]));
            Normals.Add(Vector3D.CrossProduct(vectors_array[0], vectors_array
                [1]));
            Normals.Add(Vector3D.CrossProduct(vectors_array[1], vectors_array
                [2]));
            Normals.Add(Vector3D.CrossProduct(vectors_array[1], vectors_array
                [2]));
            Normals.Add(Vector3D.CrossProduct(vectors_array[3], vectors_array
                [4]));
            Normals.Add(Vector3D.CrossProduct(vectors_array[0], vectors_array
                [2]));

            i = i + 6;
        }
```

```
                }
            }

            // add the flat back wall
            int numcorners = corners.Count;
            for (int p = 0; p < numcorners; p++)
            {
                Point3D cornertocopy = corners[p];
                corners.Add(new Point3D(cornertocopy.X, cornertocopy.Y, -this.
                    greatestDepth));
                Triangles.Add(i);
                Normals.Add(new Vector3D(0, 0, 1));
                i = i + 1;
            }


        }

        /// <summary>
        /// Create depth image from depth frame
        /// </summary>
        /// <param name="imageFrame">collection of depth data</param>
        BitmapSource DepthToBitmapSource(DepthImageFrame imageFrame)
        {
            short[] pixelData = new short[imageFrame.PixelDataLength];
            imageFrame.CopyPixelDataTo(pixelData);
            BitmapSource bmap = BitmapSource.Create(
             imageFrame.Width,
             imageFrame.Height,
             96, 96,
             PixelFormats.Gray16,
             null,
             pixelData,
             imageFrame.Width * imageFrame.BytesPerPixel);
            return bmap;
        }

        /// <summary>
        /// take a photo when button is clicked
        /// </summary>
        /// <param name="sender">object sending the event</param>
        /// <param name="e">event arguments</param>
```

```
        private void Begin_Scan_Click(object sender, RoutedEventArgs e)
        {
            //clear the canvas
            this.ClearMesh();

            // add light to the scene
            DirectionalLight DirLight1 = new DirectionalLight();
            DirLight1.Color = Colors.White;
            DirLight1.Direction = new Vector3D(0, 0, -1);

            // add a camera to the scene
            PerspectiveCamera Camera1 = new PerspectiveCamera();

            // set the location of the camera
            Camera1.Position = new Point3D(160, 120, 480);
            Camera1.LookDirection = new Vector3D(0, 0, -1);
            Camera1.UpDirection = new Vector3D(0, -1, 0);

            // create the mesh from depth data
            this.BuildMesh();

            // add texture to all the points
            tmesh.Positions = corners;
            tmesh.TriangleIndices = Triangles;
            tmesh.Normals = Normals;
            tmesh.TextureCoordinates = myTextureCoordinatesCollection;
            msheet.Geometry = tmesh;
            msheet.Material = new DiffuseMaterial((SolidColorBrush)(new BrushConverter().
                ConvertFrom("#52318F")));

            // build the scene and display it
            this.modelGroup.Children.Add(msheet);
            this.modelGroup.Children.Add(DirLight1);
            this.modelsVisual.Content = this.modelGroup;
            this.myViewport.IsHitTestVisible = false;
            this.myViewport.Camera = Camera1;
            this.myViewport.Children.Add(this.modelsVisual);
            KinectNormalView.Children.Add(this.myViewport);
            this.myViewport.Height = KinectNormalView.Height;
            this.myViewport.Width = KinectNormalView.Width;
            Canvas.SetTop(this.myViewport, 0);
            Canvas.SetLeft(this.myViewport, 0);
```

```
        }

        /// <summary>
        /// Export the completed mesh to a .obj file
        /// </summary>
        /// <param name="sender">object sending the event</param>
        /// <param name="e">event arguments</param>
        private void Export_Model_Click(object sender, RoutedEventArgs e)
        {
            //function from Helix Toolkit
            string fileName = Model_Name.Text + ".obj";

            using (var exporter = new ObjExporter(fileName))
            {
                exporter.Export(this.modelGroup);
            }

            // test code for seeing depth frame values
            Process.Start("explorer.exe", "/select,\"" + fileName + "\"");

            string fileName2 = "depth.txt";

            using (System.IO.StreamWriter file = new System.IO.StreamWriter(fileName2))
            {
                //file.Write(string.Join(",", this.Depth));
                file.Write(greatestDepth);
            }

        }

        /// <summary>
        /// Show exception info on status bar
        /// </summary>
        /// <param name="message">Message to show on status bar</param>
        private void ShowStatusMessage(string message)
        {
            this.Dispatcher.BeginInvoke((Action)(() =>
            {
                this.ResetFps();
                this.KinectStatusText.Content = message;
            }));
        }

```

```
        /// <summary>
        /// clear everything from the scene and canvas
        /// </summary>
        public void ClearMesh()
        {
            KinectNormalView.Children.Clear();
            modelGroup.Children.Clear();
            myViewport.Children.Clear();
            modelsVisual.Children.Clear();
            tmesh.Positions.Clear();
            tmesh.TriangleIndices.Clear();
            tmesh.Normals.Clear();
            tmesh.TextureCoordinates.Clear();

        }

        /// <summary>
        /// Clear canvas button click
        /// </summary>
        /// <param name="sender">object sending the event</param>
        /// <param name="e">event arguments</param>
        private void End_Scan_Click(object sender, RoutedEventArgs e)
        {
            this.ClearMesh();
        }
    }
}
```

0.2 KinectScan Graphical User Interface Code

```
ïż£<Window
        xmlns="http://schemas.microsoft.com/winfx/2006/xaml/presentation"
        xmlns:x="http://schemas.microsoft.com/winfx/2006/xaml"
        xmlns:local="clr-namespace:kinectScan"
        xmlns:sys="clr-namespace:System;assembly=mscorlib"
        xmlns:d="http://schemas.microsoft.com/expression/blend/2008" xmlns:mc="http://
            schemas.openxmlformats.org/markup-compatibility/2006" mc:Ignorable="d" x:Class
            ="kinectScan.MainWindow"
        xmlns:tk="clr-namespace:Microsoft.Kinect.Toolkit;assembly=Microsoft.Kinect.
            Toolkit"
        Title="kinectScan" Height="870" Width="1028" Loaded="WindowLoaded" Closing="
            WindowClosing" Top="0" Left="0" Icon="Images/Kinect.ico">
```

```
    <Window.Resources>

        <ResourceDictionary Source="/KinectResources.xaml" />

    </Window.Resources>

    <Grid x:Name="LayoutGrid"  Margin="0, 0, 0, 0">

        <Grid.RowDefinitions>
            <RowDefinition />
        </Grid.RowDefinitions>

        <Grid.ColumnDefinitions>
            <ColumnDefinition Width="700" />
            <ColumnDefinition Width="30" />
            <ColumnDefinition />
        </Grid.ColumnDefinitions>

        <Rectangle Fill="{StaticResource SecondaryBrandBrush}" />

        <Grid x:Name="CameraZone" Margin="0,0,0,0" TextBlock.FontFamily="{StaticResource KinectFont}" Grid.Column="0">

            <Grid.RowDefinitions>
                <RowDefinition Height="270" />
                <RowDefinition Height="30"/>
                <RowDefinition Height="30"/>
                <RowDefinition Height="510" />
            </Grid.RowDefinitions>

            <Grid.ColumnDefinitions>
                <ColumnDefinition Width="700" />
            </Grid.ColumnDefinitions>

            <!-- Depth Camera -->
            <Rectangle Fill="{StaticResource MediumNeutralBrush}" Grid.Row="0" Height="240" Width="320" Margin="30,30,350,0" />
            <Image Name="KinectDepthView" Grid.Row="0" Height="240" Width="320" Margin="30,30,350, 0"/>

            <!-- Bilateral Camera-->
            <Rectangle Fill="{StaticResource MediumNeutralBrush}" Grid.Row="0" Height="240" Width="320" Margin="350,30,30,0" />
```

```
        <Image Name="KinectRGBView" Grid.Row="0" Height="240" Width="320" Margin="350,30,30,0"/>

        <!-- Reconstruction Model -->
        <Grid x:Name="Reconstruction_Grid" Grid.Row="3">
            <Grid.ColumnDefinitions>
                <ColumnDefinition Width="30"/>
                <ColumnDefinition/>
                <ColumnDefinition Width="30"/>
            </Grid.ColumnDefinitions>

            <Grid.RowDefinitions>
                <RowDefinition Height="480"/>
                <RowDefinition/>
            </Grid.RowDefinitions>

            <Rectangle Fill="{StaticResource␣MediumNeutralBrush}" Grid.Row="3" Height="480" Width="640" Margin="30,0,30,30" />
            <Canvas Name="KinectNormalView" Grid.Column="1" Height="480" Width="640" Margin="0,0,0,30" Background="{StaticResource␣MediumNeutralBrush}"/>

            <!-- Bounding Box-->
            <!-- <Border BorderBrush="Red" BorderThickness="1" Grid.Column="1" /> -->

        </Grid>

        <!-- Titles -->
        <Label x:Name="IR_Title" Content="IR␣DEPTH␣CAMERA" Grid.Row="1" Foreground="White" HorizontalAlignment="Left" Margin="30,0,0,0" VerticalAlignment="Top"/>
        <Label x:Name="RGB_Title" Content="RGB␣CAMERA" Grid.Row="1" Foreground="White" HorizontalAlignment="Right" Margin="0,0,30,0" VerticalAlignment="Top"/>
        <Label x:Name="Model_Title" Content="RECONSTRUCTED␣MODEL" Grid.Row="2" Foreground="White" HorizontalAlignment="Center" Margin="0,0,0,0" VerticalAlignment="Bottom"/>
        <Label x:Name="statusBarText" Grid.Row="1" Foreground="White" HorizontalAlignment="Center" Margin="0,0,0,0" VerticalAlignment="Center" Grid.RowSpan="2"/>
        <Label x:Name="KinectStatusText" Content="Kinect␣Status:␣Loading..." Grid.Row="3" Foreground="White" HorizontalAlignment="Left" Margin="10,0,0,5" VerticalAlignment="Bottom"/>

```

```
        </Grid>
        <!--CameraZone-->

        <Grid x:Name="MenuArea" Background="White" Grid.Column="2">

            <Grid.RowDefinitions>
                <RowDefinition Height="90" />
                <RowDefinition Height="240" />
                <RowDefinition Height="50" />
                <RowDefinition />
                <RowDefinition Height="30" />
                <RowDefinition Height="100" />
            </Grid.RowDefinitions>

            <Grid.ColumnDefinitions>
                <ColumnDefinition Width="290" />
            </Grid.ColumnDefinitions>

            <Button x:Name ="Begin_Scan" Content="RECORD␣FRAME" Margin="0,30,0,0" Style="{StaticResource␣KinectButton}" Grid.Row="0" Click="Begin_Scan_Click"/>
            <Button x:Name ="End_Scan" Content="CLEAR␣CANVAS" Margin="137,30,0,0" Style="{StaticResource␣KinectButton}" Grid.Row="0" Click="End_Scan_Click" />

            <!--BeginSlider Area-->
            <Grid x:Name="SliderArea" Background="White" Grid.Row="1" Margin="0,0,30,30" Grid.RowSpan="2">
                <Grid.RowDefinitions>
                    <RowDefinition Height="40" />
                    <RowDefinition Height="40" />
                    <RowDefinition Height="40" />
                    <RowDefinition Height="40" />
                    <RowDefinition Height="40" />
                    <RowDefinition Height="40" />
                    <RowDefinition Height="40" />
                </Grid.RowDefinitions>

                <Grid.ColumnDefinitions>
                    <ColumnDefinition Width="220" />
                    <ColumnDefinition Width="40" />
                </Grid.ColumnDefinitions>

                <Label x:Name="Near_Filter_Title" Content="MIN␣FILTER␣DEPTH" Foreground="{StaticResource␣SecondaryBrandBrush}" HorizontalAlignment="Left"
```

```
                        Margin="10,0,0,0" VerticalAlignment="Top" Grid.Row="0" Grid.Column="0" />
                    <Slider x:Name="Near_Filter_Slider" HorizontalAlignment="Left"  Margin="10,20,0,0" VerticalAlignment="Top" Width="200" Style="{StaticResource SliderStyle}" Grid.Row="0" Grid.Column="0" Minimum="0" Maximum="654" Value="0"/>
                    <Label x:Name="Near_Filter_Value" Content="{Binding ElementName=Near_Filter_Slider,Path=Value}" ContentStringFormat="{}{0:N0}" Grid.Row="0" Grid.Column="1" Foreground="{StaticResource SecondaryBrandBrush}" HorizontalAlignment="Left" VerticalAlignment="Center" />

                    <Label x:Name="Far_Filter_Title" Content="MAX FILTER DEPTH" Foreground="{StaticResource SecondaryBrandBrush}" HorizontalAlignment="Left" Margin="10,0,0,0" VerticalAlignment="Top" Grid.Row="1" Grid.Column="0" />
                    <Slider x:Name="Far_Filter_Slider" HorizontalAlignment="Left"  Margin="10,20,0,0" VerticalAlignment="Top" Width="200" Style="{StaticResource SliderStyle}" Grid.Row="1" Grid.Column="0" Minimum="{Binding ElementName=Near_Filter_Slider,Path=Value}" Maximum="654" Value="300"/>
                    <Label x:Name="Far_Filter_Value" Content="{Binding ElementName=Far_Filter_Slider,Path=Value}" ContentStringFormat="{}{0:N0}" Grid.Row="1" Grid.Column="1" Foreground="{StaticResource SecondaryBrandBrush}" HorizontalAlignment="Left" VerticalAlignment="Center" />

                    <Label x:Name="Left_Title" Content="LEFT BOUND" Foreground="{StaticResource SecondaryBrandBrush}" HorizontalAlignment="Left" Margin="10,0,0,0" VerticalAlignment="Top" Grid.Row="2" Grid.Column="0" />
                    <Slider x:Name="Left_Slider" HorizontalAlignment="Left"  Margin="10,20,0,0" VerticalAlignment="Top" Width="200" Style="{StaticResource SliderStyle}" Grid.Row="2" Grid.Column="0" Minimum="0" Maximum="320" Value="0"/>
                    <Label x:Name="Left_Value" Content="{Binding ElementName=Left_Slider,Path=Value}" ContentStringFormat="{}{0:N0}" Grid.Row="2" Grid.Column="1" Foreground="{StaticResource SecondaryBrandBrush}" HorizontalAlignment="Left" VerticalAlignment="Center" />

                    <Label x:Name="Right_Title" Content="RIGHT BOUND" Foreground="{StaticResource SecondaryBrandBrush}" HorizontalAlignment="Left" Margin="10,0,0,0" VerticalAlignment="Top" Grid.Row="3" Grid.Column="0" />
                    <Slider x:Name="Right_Slider" HorizontalAlignment="Left"  Margin="10,20,0,0" VerticalAlignment="Top" Width="200" Style="{StaticResource SliderStyle}" Grid.Row="3" Grid.Column="0" Minimum="0" Maximum="320"
```

```
                    Value="320"/>
                <Label x:Name="Right_Value" Content="{Binding ElementName=Right_Slider, Path=Value}" ContentStringFormat="{}{0:N0}" Grid.Row="3" Grid.Column="1" Foreground="{StaticResource SecondaryBrandBrush}" HorizontalAlignment="Left" VerticalAlignment="Center" />

                <Label x:Name="Top_Title" Content="TOP BOUND" Foreground="{StaticResource SecondaryBrandBrush}" HorizontalAlignment="Left" Margin="10,0,0,0" VerticalAlignment="Top" Grid.Row="4" Grid.Column="0" />
                <Slider x:Name="Top_Slider" HorizontalAlignment="Left"  Margin="10,20,0,0" VerticalAlignment="Top" Width="200" Style="{StaticResource SliderStyle}" Grid.Row="4" Grid.Column="0" Minimum="0" Maximum="240" Value="0"/>
                <Label x:Name="Top_Value" Content="{Binding ElementName=Top_Slider, Path=Value}" ContentStringFormat="{}{0:N0}" Grid.Row="4" Grid.Column="1" Foreground="{StaticResource SecondaryBrandBrush}" HorizontalAlignment="Left" VerticalAlignment="Center" />

                <Label x:Name="Bot_Title" Content="BOTTOM BOUND" Foreground="{StaticResource SecondaryBrandBrush}" HorizontalAlignment="Left" Margin="10,0,0,0" VerticalAlignment="Top" Grid.Row="5" Grid.Column="0" />
                <Slider x:Name="Bot_Slider" HorizontalAlignment="Left"  Margin="10,20,0,0" VerticalAlignment="Top" Width="200" Style="{StaticResource SliderStyle}" Grid.Row="5" Grid.Column="0" Minimum="0" Maximum="240" Value="240"/>
                <Label x:Name="Bot_Value" Content="{Binding ElementName=Bot_Slider, Path=Value}" ContentStringFormat="{}{0:N0}" Grid.Row="5" Grid.Column="1" Foreground="{StaticResource SecondaryBrandBrush}" HorizontalAlignment="Left" VerticalAlignment="Center" />
            </Grid>
            <!--EndSliderArea-->

            <!--Begin Radio-->
            <Label x:Name="Filter_Type_Title" Content="FILTER TYPE" Foreground="{StaticResource SecondaryBrandBrush}" HorizontalAlignment="Left" Margin="10,0,0,0" VerticalAlignment="Top" Grid.Row="2" />
            <RadioButton Name="Filter_Off" Content="Off" HorizontalAlignment="Left" Margin="10,30,0,0" Grid.Row="2" VerticalAlignment="Top" IsChecked="True" />
            <RadioButton Name="Filter_Blur" Content="Blur" HorizontalAlignment="Left" Margin="60,30,0,0" Grid.Row="2" VerticalAlignment="Top" />
            <!--End Radio-->

```

```
                <!--ModelNameArea-->
                <Grid x:Name="ModelNameArea" Grid.Row="4">
                    <Grid.RowDefinitions>
                        <RowDefinition />
                    </Grid.RowDefinitions>

                    <Grid.ColumnDefinitions>
                        <ColumnDefinition Width="100" />
                        <ColumnDefinition />
                    </Grid.ColumnDefinitions>
                    <Label x:Name="Name_Label" Content="MODEL NAME:" Foreground="{StaticResource SecondaryBrandBrush}" HorizontalAlignment="Left" VerticalAlignment="Top" Grid.Column="0" Margin="7,0,0,0" />
                    <TextBox x:Name="Model_Name" Text="modelName"  HorizontalAlignment="Left" VerticalAlignment="Top" Width="140"  Margin="17,0,0,0" Grid.Column="1" />
                </Grid>
                <!--EndModelNameArea-->

                <Button x:Name ="Export_Model"  VerticalAlignment="Bottom" Margin="50,0,0,23" Style="{StaticResource KinectButton}" Grid.Row="5" Click="Export_Model_Click">
                    <StackPanel Orientation="Horizontal">
                        <Label x:Name="Export_Label" Content="EXPORT MODEL" Foreground="White" FontFamily="{StaticResource KinectFont}" FontSize="14" Padding="0,0,10,0"/>
                        <Image x:Name="Download" Source="Images/download.png"  Width="23" Height="23" HorizontalAlignment="Left" VerticalAlignment="Top" />
                    </StackPanel>
                </Button>
                <!-- <TextBox Name="test_text" HorizontalAlignment="Left" Height="109" Margin="42,124,0,0" Grid.Row="3" TextWrapping="Wrap" Text="TextBox" VerticalAlignment="Top" Width="209"/> -->
            </Grid>
            <!--MenuArea-->
            <tk:KinectSensorChooserUI Name="sensorChooserUI" HorizontalAlignment="Center" Margin="330,0,330,5"/>
        </Grid>
        <!--LayoutGrid-->

</Window>
```

References

[1] How kinect and kinect fusion (kinfu) works, December 2011.

[2] Helmut Grabner Xiaofeng Ren-Kurt Konolige Andrea Fossati, Juergen Gall, editor. *Consumer Depth Cameras for Computer Vision Research Topics and Applications*. Springer-Verlag London, 2013.

[3] Richard A. D'Aveni. 3-d printing will change the world. *Harvard Business Review*, 2013.

[4] Lesliei Gordon. The changing face of 3d printing. *Machine Design*, 2013.

[5] Satoshi Tanaka Soo-Hyun Park Jong-Hyun Kim, Kangsun Lee. *Advanced Methods, Techniques, and Applications in Modeling and Simulation*. Springer Japan, 2012.

[6] Ashlee Vance. 3-d printing spurs a manufacturing revolution. *New York TImes*, 2010.