Dental restoration is the designed materials used to replace the missing teeth to restore function and morphology. One of the most common types is a bridge, which consists of one or more artificial teeth anchored by crowns at each end. To fill the gap between the pontic and the crowns, the open space must be bridged to avoid teeth shifting. This bridge is manually designed for each patient and takes long time to create. Therefore, this paper presents the method for computer aided design using Borland C++ Builder® and OpenGL to create the crowns that cover the abutment teeth and the bridge that fills the space between each tooth by 3D object modeling from 3D scanned dental data. Our technique starts from opening files of the scanned teeth in STL format and selecting the desired surfaces to generate the offset by defining the landmarks and fitting them with cubic spline algorithm. Then the segmentation by region growing is processed to obtain the crown surfaces which can also be adjusted by size scaling. Next, the pontic is selected from the tooth library and the program will create the connector on the user defined area based on spline technique. The result has shown that our method can be used to develop the program for design of the dental bridge to fit on individual that can reduce the production time and also ease to transfer to computer aided production equipment.

INTRODUCTION
Dental restoration is a necessary treatment when teeth are missing. One of the most common types is a bridge, which are non-removable appliances for replacing one or more missing teeth. A typical dental bridge is made up of a pontic or a false tooth attached to two crowns that cover the surrounding abutment teeth. Therefore, the bridge needs the appropriate design to fit on individual. Conventionally, the crowns and bridgework require the skill and experience of dental technician. It also needs many processes and takes long time to complete. The novel technique with computer aided design and fabrication has been presented to help these processes. However, the commercial system for design crowns and bridgework such as CEREC [1], DentalDesigner™ [2], etc, still have high cost and show no revealed source code. For this reason, the software tool for the design of the bridge application has been initially developed to use in house. In this paper, the processes for bridge design are presented in two main parts, creating crowns and creating connectors to bridge the gap between each object.

METHODS
Creating Crowns
First of all, patient’s dental cast is scanned by the CT scanner and reconstructed into 3D computer...
model in STL file format, which contains the geometry of the object in the forms of triangular faces, vertices and their normal directions. Our software has been written using Borland C++ Builder® and OpenGL to manage this STL model. The aim is to design the crown to fit on the teeth by the offset process. This comprises of the making of 3 surfaces on the tooth: the internal surface, the external surface that covers the tooth, and the external surface that links the covering and the internal surfaces [3]. First, the margin where the crown meets the abutment must be identified. User is allowed to select the landmarks around the tooth with any number of points and the program will fit curve to the closed shape to obtain the required surface from the original tooth. This step uses the three-dimensional cubic spline interpolation to fit line on this boundary, which is applied from one-dimensional cubic spline fitting in Numerical Recipes in C [4,5,6]. The interpolated curve is constrained to pass through all user defined landmarks. However, the 3D point locations of the fitting curve must be transformed to the nearest 3D vertices of the STL structure for indexing the edge of the region. Once we define the boundary of the offset, we then apply the region growing on this area to segment the surface of the tooth.

For the segmentation process, it only needs an arbitrary seed inside the region of interest. Then, the region is grown from the seed by checking the neighbor faces of the STL structure. The algorithm searches for the object’s faces that stay inside the edged vertices and adds them to increase the size of the region. When the growth stops, the area of the offset is obtained and noticed by color labeling [7]. This segment is defined as the internal surface of the crown, which initially has the same figure as the abutment. Next, the labeled vertices are offset by scaling the vertices along the normal vector of each vertex in proportion to user interface. So the thickness of the offset can be adjusted to suit the abutment and surrounding area. After that, the program will automatically connect the border of the offset surface and the internal surface together to create the closed surface.

Creating Connectors
In this paper, the program has been initially written for design a bridge that replaces one missing tooth. A bridge for more than 1 tooth is not mentioned. The absent tooth called a pontic is selected from the standard tooth model with proper shape, size and function. Additional adjustment for the physical features can also be done in the program. However, there is the gap between the designed crown and the pontic needed to be connected. Therefore, the algorithm for 3D object connection is performed for bridging them together. The desired surfaces for creating the connector of both sides are selected by defining the landmarks with any number of points. Then the center of each landmark set is calculated. The Euclidian distance vectors between the landmarks and their center are all determined. The matching starts from finding the angle between first vectors of landmark set 1 and all vectors of landmark set 2. The angle between vectors is calculated using dot product of vectors. The vector of set 2 that gives the minimum angle value is paired to the first landmark of set 1. After that other vector pairs are computed subsequently without duplication. Then the cylinder-like model is created for bridging the space with these arranged points. To illustrate this model in OpenGL, three points from both surfaces are matched to draw triangular primitives connectedly to form the 3D cylinder. The completed 3D viewing also concerns the lighting that applies on the model. So the normal vector that points out of each triangular surface must be
calculated to make the lighting looks naturally [8]. Moreover, the connector can be adjusted to the most suitable size and shape by dividing the connector into 1-10 sections according to the user interface. Each section can be scaled its cross section and smoothly linked together by applying the spline technique.

RESULTS

The experiment results with our tooth model have shown that the program can be used to view the 3D tooth model from STL files according to the user interface viewing. The offset representing the crown part of the bridge can be created from the 3D segmentation by region growing within the margin on the abutment surfaces as demonstrated in Figure 1. Figure 1a shows the landmarks from user interactions that are fitted to the closed line and transformed to vertices of the STL model. The region growing inside the defined boundary is labeled with the red region shown in Figure 1b. The labeled surfaces are offset with some thickness to make the crown that can cover the tooth is shown in Figure 1c. Our resulted bridge is shown in Figure 2, which is from the prepared abutment. Figure 2a illustrates the adjustable connector between teeth and Figure 2b and Figure 2c result our designed bridge in different views.

(a)                      (b)                                               (c)

Figure 1 The procedure of making offset (a) Define landmarks and fit on vertices of the STL model, (b) Perform the region growing and (c) Make thickness to the offset to produce the crown

(a)                      (b)                                               (c)

Figure 2 The resulted bridge from the program
DISCUSSION AND CONCLUSION

We have presented here the process of the computer aided dental bridge design for an alternative choice, while the conventional process is done manually. With the method to offset the triangular mesh of the abutment surfaces and the 3D object connection between teeth, the design of the bridge can be performed with some user interaction. The results have shown the well design on our tooth model. The next step is to be more adjustable on the bridge shape and surface to the most suitable anatomical features with additional consideration on the occlusion. Moreover, automatic segmentation would be applied on the offset process to require little to no user interaction and more accurate surface labeling at the margin. Furthermore, the regularization on the creating model would be performed to repair some defective triangular mesh for the perfect manufacturing step.

REFERENCES