THE DEVELOPMENT OF MODEL ANALYZER

IN

ORTHODONTICS

SUKIT EIMTAVEECHARERN

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The objective of this thesis is to study and develop a system for measuring and analyzing the tooth size to aid orthodontists in treatment planning. The advantages compared to the conventional technique are shorter time and higher simplicity. The system consists of four digital cameras, a stand, an electronics circuit, and a software program. The electronics circuit is used for controlling the cameras, while the program is used to capture the image from the cameras. The system being developed in this thesis uses the non-contact measurement technique in order to reduce errors due to mechanical movement. This system measures the tooth size by using four videoconference cameras, which are easy to find and cheap. The result can be partly used in the real measurement system. That is, the system can be used to measure the front tooth with an acceptable error. Anyway, the tooth side measurement produces higher errors due to the quality of lens and the camera position. Therefore, this part still cannot be used in the real measurement system.

Unfortunately, though the result of this technique can reduce enormous errors due to mechanical movements, there is an error due to the quality of lens and camera position. Therefore, further development is required to eliminate this error by improving the lens quality, or using higher calibration techniques.

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จุดประสงค์ของการวิจัยครั้งนี้ เพื่อพัฒนาเครื่องมือวิเคราะห์ขนาดฟันจากแบบพิมพ์ฟันด้วยระบบดิจิตอล เพื่อช่วยในการวางแผนการจัดฟันให้มีประสิทธิภาพมากยิ่งขึ้น และเครื่องมือนี้จะช่วยให้การวัดเป็นไปได้ง่าย และรวดเร็วกว่าการวัดแบบดั้งเดิม โดยเครื่องมือนี้ประกอบด้วย กล้องถ่ายวิดีโอแบบดิจิตอลขนาดเล็ก 4 ตัว และแท่นยึด ซึ่งออกแบบมาให้เหมาะสมกับการถ่ายภาพฟัน นอกจากนั้นยังมีวงจรอิเล็กทรอนิกส์ สำหรับสั่งงานให้กล้องทำงาน และโปรแกรมในการควบคุมกล้องให้ถ่ายภาพ แล้วนำภาพที่ได้ไปประมวลผล โดยเทคนิคที่ใช้ในเครื่องมือชนิดนี้เป็นแบบ non-contact measurement ทำให้สามารถลดความผิดพลาดทางกลศาสตร์ได้อย่างสิ้นเชิง และกล้องถ่ายวิดีโอที่ใช้ในการศึกษาครั้งนี้ สามารถหาซื้อได้ง่าย และมีราคาถูก โดยผลที่ได้สามารถนำไปใช้ในระบบการวัดจริงได้ระดับหนึ่ง กล่าวคือ สามารถวัดขนาดฟันหน้าได้ถูกต้องแม่นยำ โดยมีค่าความผิดพลาดที่ยอมรับได้ แต่การวัดขนาดฟันทางด้านข้างนั้น ยังไม่สามารถนำไปใช้ในการวิเคราะห์จริงได้ เนื่องจากขนาดที่วัดได้ยังมีค่าความผิดพลาดสูงอยู่ ซึ่งเป็นผลจากคุณสมบัติของเลนส์ และตำแหน่งของกล้อง

ถึงแม้ว่าการวัดระบบดิจิตอล จะสามารถลดความผิดพลาดทางกลศาสตร์ไปได้มาก แต่จากการศึกษาครั้งนี้พบว่ายังมีความผิดพลาดเกิดขึ้นดังที่ได้กล่าวมาแล้วข้างต้น ซึ่งจะต้องทำการศึกษาต่อไป เพื่อหาทางลดความผิดพลาดนี้ โดยแนวทางแก้ไขสามารถทำได้โดยการปรับปรุงคุณภาพของกล้อง หรือ ใช้เทคนิคการวัดที่มีความทันสมัยมากขึ้น

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CHAPTER I

INTRODUCTION

Nowadays, esthetics has become a major aspect of life. People have paid much attention on creating and maintaining their beauty. Orthodontics is one of the treatment choices, which has become very famous among Thai people during these decades. Moreover, functionality and stability are the other two reasons for the existence of orthodontics. Therefore, orthodontics is a way of treatment by rearranging the malalign teeth into the correct position by the orthodontists. The appliance that is used for adjusting the tooth position is called braces. The brace exerts the force to straighten the tooth through the thin wire that highly resists the corrosion and is flexible for shaping. The process of tooth arrangement takes quite a long time for adjusting the teeth in the desired position. The reason is because the tooth cannot be easily moved. Therefore, the orthodontist has to carefully plan for the treatment and follow the procedure in order to get the required result. The period of treatment is also varied among different treatments. Moreover, various informations have to be taken from the patient before starting the treatment.

There are a lot of parameters that are concerned in planning. Dental casts and x-ray films are mainly used for determining the information. Tooth size is one of the important parameter that is measured from the dental cast. This information can be used for predicting the permanent tooth size in children whose permanent tooth has not been erupted yet. It is also used to determine whether all of the permanent tooth will fit the jaw or not. Unfortunately, all the required information is usually measure manually by the orthodontists using the caliper, which takes time and may not be accurate.

Though there are various commercial available software in orthodontics, the price is very expensive. Moreover, the result is more suitable to American standard than Thai standard. Some researches (1) have been done to provide the appropriate result that is suitable for Thai people. Unfortunately, none of these informations are developed in this kind of program.

Therefore, the goal of this project is to develop an analyzer that can measure and analyze the dental cast data for aiding orthodontists in providing a faster diagnosis. The system is mainly divided into two main parts. The first part is the hardware part, which consists of four videoconference cameras with an electrical switching circuit. The other part is the software part, which measures and calculates the data from the dental cast. The software process is to digitize the dental cast data, then analyze these data by calculating the result using any input orthodontic equations.

The advantage of this system over the traditional system is flexibility. However, the time spent learning how to use the system must be as short as possible with respect to its usefulness.

PROJECT OBJECTIVES

- To study the basic of orthodontics and the techniques involved.
- To study the measurement of 3D objects by matching information of projected data from different views.
- To develop a model analyzer system for measuring the dental cast information that is used in orthodontic treatment planning.

- To develop software for calculating and analyzing the dental cast information using orthodontic equations.

PROJECT BENEFITS

- **Increase the effectiveness of analysis and diagnosis for orthodontic treatment**

  Doctors can utilize dental cast information with greater ease and flexibility.

- **Expand the knowledge base**

  Provides greater opportunity for further development in the field of orthodontics, such as developing further orthodontics equations or gain higher image processing capabilities.

- **Cost reduction**
  - reduce the use of document works
  - reduce the work of dental casts storage

SCOPE OF THIS PROJECT

The scope of this project is to develop a model analyzer to measure and calculate dental cast data. The system of the analyzer must be able to digitize the dental cast information, measure the tooth size, and calculate the result using orthodontic equations. Moreover, all these informations can be stored in the patient's database to provide future information access.

CHAPTER II

LITERATURE REVIEW

I. Orthodontics

Orthodontics is a branch of dentistry concerned with the study of the complicated growth of the craniofacial bones, the development of occlusion and the treatment of dentofacial abnormalities. Therefore, orthodontic therapy is directed to the treatment of abnormal occlusion of the teeth, and craniofacial bones. Combinations of these abnormalities may cause various consequences, such as impaired mastication, unfortunate facial esthetics, dysfunction of the temporomandibular articulation, or impaired speech.

Orthodontics involves the three primary tissue systems concerned in dentofacial development, namely, the craniofacial skeleton, facial musculature and jaw musculature. By means of suitable appliances, the individual teeth can be positioned more favorably to provide better esthetics, occlusal function, oral health and speech. Correction of the craniofacial skeleton, however, is a different matter, since it is much more difficult to alter the craniofacial skeleton than it is to position teeth. However, it is possible to direct the growth of the craniofacial skeleton in young children. In older patient whose facial growth is more completed, the teeth are positioned to function better and to camouflage any disharmonies of the facial skeletal pattern.

1. Types of malocclusion

Occlusion is an important parameter that is concerned about in orthodontics. Orthodontists try to move the teeth to the correct position that is called normal occlusion. The normal occlusion is the best position of teeth that give a good function and stability of the teeth. The teeth arrangement that is not aligning in normal occlusion is called malocclusion.

The malocclusion can be divided into two types.

1.1 Dentoalveolar type: the malocclusion that occurs from the disorder of teeth and alveolar bone.

1.2 Skeletal type: the disorder of jaw structure.

2. Orthodontic treatment plans

There are two primary causes of the malocclusion, which are heredity and environment. Examples of the causes are premature loss of deciduous teeth, abnormal oral habit, and congenital deformities (cleft lip and cleft palate). These factors have an effect in different types of the malocclusion such as crowding, openbite, deepbite and crossbite. Therefore, orthodontics plans could be discriminated as listed below.

2.1 Preventive orthodontics

This treatment helps to prevent malocclusion. A good treatment should be perform during deciduous teeth. The treatments are plugging proximal milk tooth , crowning, and space maintainer.

2.2 Interceptive orthodontics

For the interceptive plan, treatment is for patients in an initially stage that has mixed dentition. Examples of the treatments are crossbite fixation, changing abnormal oral habit and fixing in skeletal disharmony.

2.3 Corrective orthodontics

This technique is used in permanent dentition. It is used for complicated problems that may involve the removal of permanent tooth.

3. Teeth parameter in Orthodontics

Various information are required for planning in orthodontic treatment, including the patient history, clinical assessment data, tooth model, cephalogram, orthopantomograph, etc. The tooth model analysis is an important source of data in orthodontics because the orthodontist can analyze the morphology of the patient's tooth from this model.

3.1 Tooth size

There is a strong evidence that tooth sizes vary individually from person to person. The factors include nationality, facial skeletal structure, and environmental influences. Moreover, there are some researches, which study about the relationship between tooth size and nationality. The result clearly shows the differences in tooth size between nationality and also geniality. Further research has been done to implement new formula, which is suitable to Thai people. One frequently encounters in dental practice marked disharmony between the size of the teeth and the bones in which they are placed. Tooth size and bone size seem to be under separate genetic control mechanisms, an unfortunate biologic problem for clinical orthodontic practice.

- **Individual Teeth**

When considering the size of teeth, several measurements and concepts are involved. The word "arch" is used to designate any or the entire dimension shown in Figure 1.

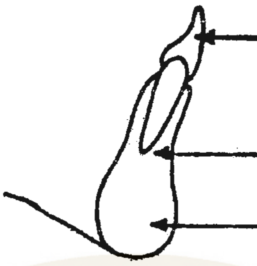

Figure 1 The relationship of the three arches. (1)

The basal arch is the arch formed by the corpus mandibularies or maxillaries. Its dimensions probably are unaltered by the loss of all permanent of the apical base.

The alveolar arch is the arcal measurement of the alveolar process. The dimensions of the alveolar arch may not coincide with those of the basal arch if, for example, the teeth are tipped labially of the basal arch.

The dental arch usually is measured through the contact points of teeth and represents a series of points where the muscle forces acting against the crowns of the teeth are balances. When the crowns are tipped markedly off the basal bone, the dental arch and alveolar arch are not synonymous.

For orthodontic diagnostic purposes, size of teeth is entirely a relative matter. Large teeth do not always result in a malocclusion, since the available space may be sufficiently large to include them nicely. Comparisons of tooth size and available space, determination of the effects of the size of the teeth on overbite and overjet and the identification of disharmonies of tooth size within the arch is, however, of great clinical import.

The localization of intra-arch and inter-arch disharmonies and their implications to treatment planning are aided by use of the Bolton Teeth Ratio Analysis.

- **Size relationship of groups of teeth**

Bolton tooth ratio analysis

Bolton studied the interarch effects of discrepancies in tooth size to devise a procedure for determining the ratio of total mandibular versus maxillary tooth size. Study of these ratios help in estimating the overbite and overjet relationships that will obtain after treatment is finished, and the effects of contemplated extraction of occlusal misfit produced by inter-arch tooth size incompatibilities.

Figure 2 is the suggested data for use in recording and computing both the overall and anterior tooth ratios.

Over-all Ratio

$\frac{\text{Sum mandibular 12 \_\_ mm.}}{\text{Sum maxillary 12 \_\_ mm.}}$ = ___ x 100 = ___ % Over-all ratio

Mean 91.3 ± 0.26
S. D. (σ) 1.91
Range 87.5 - 94.8

Maxillary 12	Mandibular 12	Maxillary 12	Mandibular 12	Maxillary 12	Mandibular 12
86	77.6	94	85.8	103	94.0
86	78.5	95	86.7	104	95.0
87	79.4	96	87.6	105	95.9
88	80.3	97	88.6	106	96.8
89	81.3	98	89.5	107	97.8
90	82.1	99	90.4	108	98.6
91	83.1	100	91.3	109	99.5
92	84.0	101	92.2	110	100.4
93	84.9	102	93.1		

Patient Analysis

If the over-all ratio exceeds 91.3 the discrepancy is in excessive mandibular arch length. In above chart locate the patient's maxillary 12 measurement and opposite it is the correct mandibular measurement. The difference between the actual and correct mandibular measurement is the amount of excessive mandibular arch length.

______ - ______ = ______
Actual mandibular 12 - Correct mandibular 12 = Excess mandibular 12

If over-all ratio is less than 91.3:

______ - ______ = ______
Actual maxillary 12 - Correct maxillary 12 = Excess maxillary 12

Anterior Ratio

$\frac{\text{Sum mandibular 6 \_\_ mm.}}{\text{Sum maxillary 6 \_\_ mm.}}$ = ___ x 100 = ___ % Anterior ratio

Mean 77.2 ± 0.22
S. D. (σ) 1.65
Range 74.5 - 80.4

Maxillary 6	Mandibular 6	Maxillary 6	Mandibular 6	Maxillary 6	Mandibular 6
40.0	30.9	45.5	35.1	50.5	39.0
40.5	31.3	46.0	35.5	51.0	39.4
41.0	31.7	46.5	35.9	51.5	39.8
41.5	32.0	47.0	36.3	52.0	40.1
42.0	32.4	47.5	36.7	52.5	40.5
42.5	32.8	48.0	37.1	53.0	40.9
43.0	33.2	48.5	37.4	53.5	41.3
43.5	33.6	49.0	37.8	54.0	41.7
44.0	34.0	49.5	38.2	54.5	42.1
44.5	34.4	50.0	38.6	55.0	42.5
45.0	34.7				

Patient Analysis

If anterior ratio exceeds 77.2:

______ - ______ = ______
Actual mandibular 6 - Correct mandibular 6 = Excess mandibular 6

If anterior ratio is less than 77.2:

______ - ______ = ______
Actual maxillary 6 - Correct maxillary 6 = Excess maxillary 6

Figure 2 The Bolton analysis of tooth size discrepancies. The size of the individual teeth are measured and recorded on the form. The anterior and the overall ratio are computed separately. (2)

In order to obtain the analysis result, several measurements have to be performed. The first step is to divide the sum of the widths of the 12-teeth mandibular by the sum of the 12- teeth maxillary, then multiply by 100. The result is a mean ratio, which represents an overbite-overjet relationship (Figure3) as well as posterior occlusion. According to Bolton, a mean ratio of 91.3 will result in ideal overbite-overjet relationships as well as posterior occlusion. If the overall ratio exceeds 91.3, the discrepancy is due to excessive mandibular tooth material. The difference between the actual and the desired mandibular measurement is the amount of excessive mandibular tooth material when the ratio is greater than 91.3. If the ratio is less than 91.3, the difference between the actual maxillary size and the desired maxillary size is the amount of excess maxillary tooth material.

A similar ratio (anterior ratio) is computed for the 6 anterior teeth (incisors and cuspids.). The desired anterior ratio is 77.2, which will provide ideal overbite and overjet relationships of the angulation of the incisors. If the anterior ratio exceeds 77.2, there is excess mandibular tooth material. If it is less than 77.2, there is excess maxillary tooth material.(3)

Moreover there is a study to investigate the tooth size in Thai population with normal occlusion. The anterior ratio is 78.53, which will provide ideal overbite and overjet relationships of the angulation of the incisors. The posterior ratio is 104.9 and between or upper teeth and lower teeth is 92.

3.2 Alignment

This parameter is a fundamental objective of any orthodontic treatment plan. Therefore, any assessment of quality of orthodontic result must contain an assessment of tooth alignment. In the anterior region, the incisal edges and lingual surfaces of the maxillary anterior teeth, and the incisal edges and labial-incisal surfaces of the mandibular anterior teeth are chosen as the guide to assess anterior alignment. These are not only the functional area of the teeth, but they also affect esthetics if they are not arrange in proper relationship. In the maxillary posterior region, the mesiodistal central groove of the premolars and molar is used to assess adequacy of alignment. In the mandibular arch, the buccal cusps of the premolars and molars are used to assess proper alignment. These areas were chosen since they represent easily identifiable points on the teeth, and represent the functioning areas of the posterior teeth. The results of the four field tests show that the most commonly malaligned teeth were the maxillary and mandibular lateral incisors and second molars, which accounted for nearly 80% of the mistakes.

3.3 Buccolingual inclination

This parameter is used to assess the buccolingual angulation of the posterior teeth. In order to establish proper occlusion in maximum intercuspation and avoid balancing interfaces, there should not be a significant difference between the heights of the buccal and lingual cusps of the maxillary and mandibular molars and premolars. The directors use a special step gauge to assess this relationship. Some latitude is allowed; however, in past field tests significant problems were observed in the buccolingual inclination of the maxillary and mandibular second molars.

3.4 Occlusal relationship

This parameter is used to assess the relative anteroposterior position of the maxillary and mandibular posterior teeth. In order to achieve accuracy and reliability in measuring this relationship, these criteria uses the Angle's relationship. Therefore, the buccal cusps of the maxillary molars, premolars, and canines must align within 1 mm. of the interproximal embrasures of the mandibular posterior teeth. The mesiobuccal cusp of the maxillary first molar must align within 1 mm of the buccal groove of the mandibular first molar.

3.5 Occlusal contacts

This parameter is measured to assess the adequacy of the posterior occlusion. Since a major objective of orthodontic treatment is to establish maximum intercuspation of opposing teeth, the functioning cusps are used to assess the adequacy of this criterion, such as the buccal cusps of the mandibular molars and premolars, and the lingual cusps of the maxillary molars and premolars. If cusps form is small or diminutive, that cusps is not scored. In past field tests, the most common problem is inadequate contact between maxillary and mandibular second molars. (4)

3.6 Overjet and Overbite

- Overjet is the horizontal overlap of the incisor.
- Overbite is the vertical overlap of the incisor.

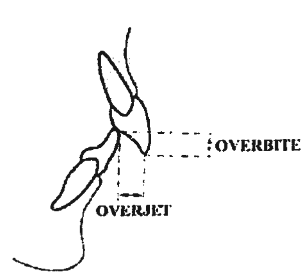

Figure 3 The overjet and overbite (2)

During the primary dentition, the overbite decrease slight amount, although the overjet often is reduced to zero. From the early mixed dentition to late adolescence, the overbite increases (between 9 and 12 years) and then decreases.

Overbite is correlated with a number of vertical facial dimensions, notably ramus height, whereas overjet usually is a reflection of the anteroposterior relationships of the maxillary and mandibular denture bases.

Overjet is used to assess the relative transverse relationship of the posterior teeth, and the anteroposterior relationship of the anterior teeth. In the posterior region, the mandibular buccal cusps and maxillary lingual cusps are used to determine proper position within the fossae of the opposing arch. In the anterior region, the mandibular incisal edges should be in contact with the lingual surfaces of the maxillary anterior teeth. In past field tests, the common mistakes in overjet have occurred between the maxillary and mandibular incisors and second molars. This parameter can not be measured if there is no contact between the upper and lower incisor, which is called openbite.

3.7 Interproximal contacts

This parameter is used to determine whether all the spaces within the dental arch have been closed or not. Persistent spaces between teeth after orthodontics therapy are not only unaesthetic, but can lead to food impaction.

3.8 Root angulation

This parameter is used to assess how well the roots of the teeth have been positioned relative to one another. Although the panoramic radiograph is not the perfect record for evaluating root angulation, it is probably the best means possible for making this assessment. If roots are properly angulated, then sufficient bone will be present between adjacent roots, which could be important of the patient were susceptible to periodontal bone loss at some point in time. If roots are increase in diameter, then they are not graded. In past field tests, the common mistakes in root angulation occurred in the maxillary lateral incisors, canines, and second premolars, and mandibular first premolars.

4. Dental Model

The record dental casts are one of the most important sources of information for the dentist doing orthodontic treatment. A good set of dental casts should show the alignment of the teeth and the alveolar processes as far as the impression material can displace the soft tissue. From the occlusal view, one can analyze the arch form, arch asymmetry, alignment of the teeth, palate shape, tooth size, tooth shape, rotations of teeth, etc. While holding the casts together in the usual occlusal position, the occlusal relationships can be observed as well as midline coincidence, attachment of the frena, the occlusal curve and axial inclinations of teeth.

5. Analysis of tooth development

5.1 Calcification

Calcification standards derived from population of children may be used in the following ways:

- To compare the individual patient to an appropriate population in order to determine whether his dental development is normal, advanced
- To compare the child to his own pattern of development

- To predict the time of completion of root development, diminution of pulp size or intra-oral eruption. The stages of development are ordinal stages, it must not be assumed.

Before planning any orthodontic treatment in the mixed dentition, it is essential to know the developmental status of each individual tooth and the probable time each tooth will achieve future development stages. The use of group averages simply is not sophisticated enough for a practical clinical analysis.

5.2 Eruption

A crude rule of thumb for predicting eruption is utilizing Nolla's stages. Figure 4 Movement begins when the crown formation is complete. The crest of alveolar process is pierced when root is roughly two-thirds completed. Intra-oral emergence occurs when three-fourths of the root is formed. Occlusion is achieved when the root length is almost completed but the apex is still open.

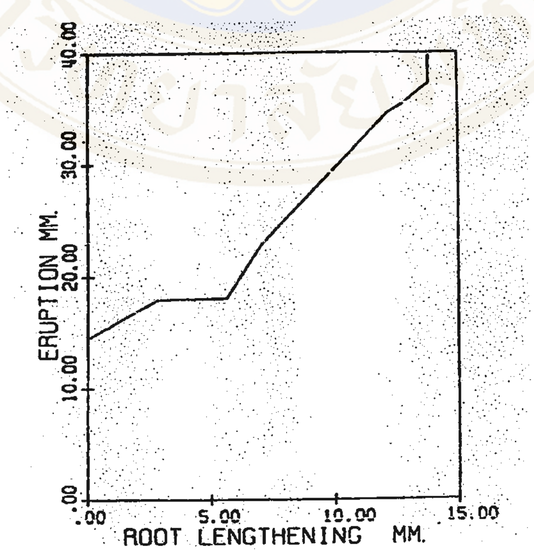

Figure 4 A computer plots showing the relationship between root lengthening and eruption. This plot is a single mandibular cuspid. "Root lengthening" is a measure of

total tooth length including crown high. "Eruption" is the distance from the lower border of the mandible. The plateau in the curve coincides with the completion of the crown. The most accelerated period occurs just after crown completion. Little, if any, eruption occurs prior to crown completion. (5)

By referring to Table 1, one can, in a crude way, predict the eruption of an individual tooth in the following fashion. By comparing the individual patient's deviations from the normal pattern, crude estimates of the time of piercing the alveolar crest and reaching occlusal contact can be made. Note that these estimates are based on the time of piercing of the alveolar crest, not the gingival emergence.

Table 1 Norms for Maturation of permanent teeth for boys (NOLLA) (Mean stage of calcification for each tooth is shown in terms of the 10 stages of calcification) (2)

Age, Yr.	Mandibular Teeth (Growth Stage)								Maxillary Teeth (Growth Stage)							
	1|1	2|2	3|3	4|4	5|5	6|6	7|7	8|8	1|1	2|2	3|3	4|4	5|5	6|6	7|7	8|8
3	5.2	4.5	3.2	2.6	1.1	5.0	0.7	—	4.3	3.4	3.0	2.0	1.0	4.2	1.0	—
4	6.5	5.7	4.2	3.5	2.2	6.2	2.0	—	5.4	4.5	3.9	3.0	2.0	5.3	2.0	—
5	7.5	6.8	5.1	4.4	3.3	7.0	3.0	—	6.4	5.5	4.8	4.0	3.0	6.4	3.0	—
6	8.2	7.7	5.9	5.2	4.3	7.7	4.0	—	7.3	6.4	5.6	4.9	4.0	7.4	4.0	—
7	8.8	8.5	6.7	6.0	5.3	8.4	5.0	0.8	8.2	7.2	6.3	5.7	4.9	8.2	5.0	—
8	9.3	9.1	7.4	6.8	6.2	9.0	5.9	1.4	8.8	8.0	7.0	6.5	5.8	8.9	5.8	1.0
9	9.7	9.5	8.0	7.5	7.0	9.5	6.7	1.8	9.4	8.7	7.7	7.2	6.6	9.4	6.5	1.8
10	10.0	9.8	8.6	8.2	7.7	9.8	7.4	2.0	9.7	9.3	8.4	7.9	7.3	9.7	7.2	2.3
11	—	—	9.1	8.8	8.3	9.9	7.9	2.7	9.95	9.7	8.8	8.6	8.0	9.8	7.8	3.0
12	—	—	9.6	9.4	8.9	—	8.4	3.5	—	9.95	9.2	9.2	8.7	—	8.3	4.0
13	—	—	9.8	9.7	9.4	—	8.9	4.5	—	—	9.6	9.6	9.3	—	8.8	4.9
14	—	—	—	10.0	9.7	—	9.3	5.3	—	—	9.8	9.8	9.6	—	9.3	5.9
15	—	—	—	—	10.0	—	9.7	6.2	—	—	9.9	9.9	9.9	—	9.6	6.6
16½	—	—	—	—	—	—	10.0	7.3	—	—	—	—	—	—	10.0	7.7
17	—	—	—	—	—	—	—	7.6	—	—	—	—	—	—	—	8.0

- **Number of eruption**

Counting must include not only the teeth seen but also that developing- or not- within the jaws. Particular mention should be made of the congenital absence of teeth. Reference of Nolla's data provides help for determination of the congenital absence of teeth. For example, if a boy 8 years has not begun to calcify his mandibular third molar, the region should be studied regularly with radiographs, since the average boy begins calcification of mandibular third molars at age 7.

- **Measurements of dental arch width after eruption of the first premolars**

The reference points for measurements in the maxillary and mandibular arch are defined so that in an anatomically correct occlusion, the upper and lower points are directly opposed.

Definition of reference points

Maxilla = posterior groove of the transverse fissure of the first deciduous molar.

Mandible = distobuccal cusp tip of first deciduous molar.

Maxilla anterior = lowest point of the transverse fissure of the first premolar.

Maxilla posterior = point intersection of the transverse fissure with the buccal fissure of the first permanent premolar.

Mandible anterior = facial contact point between first and second premolars.

Mandible posterior = tip of the mesiobuccal cusp of the lower first permanent molar

The anterior arch width is defined as the distance between the anterior reference points (premolar region). The posterior width is the distance between the first molar. The posterior arch width is measured exclusively in the region of the 6-year-molars.

6. Dimensional Changes in the Dental Arches

Three set of measurements often are confused

- The combined widths of the teeth
- The dimensions of the dental arch in which the teeth are arrayed
- The dimensions of the mandible of maxilla proper, that is, the so-called basal bone.

The dental arch size and shape are first determined by the cartilaginous skeleton of the fetal maxilla and mandible. A close relationship then develops between the tooth germs and growing jawbones. Only during the postnatal period do the environmental forces acting against the crowns of the teeth affect the dental arch size and shape. Dental arch size does not correlate well with the size of the teeth contained within it. The parameters, which determine the usual arch dimensions are, as shown in figure 5.

- widths at the canines, primary molars and first permanent molars
- length
- circumference

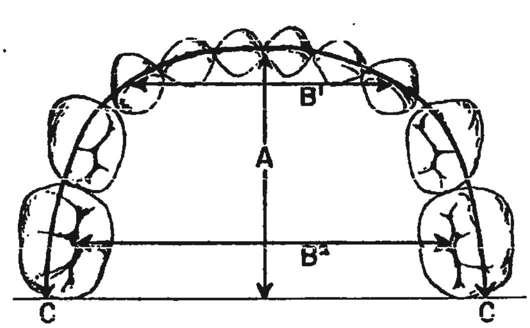

Figure 5 Arch dimensions. A, arch length. B^1 bicanine diameter. B^2, bimolar diameter, C-C, arch perimeter or arch circumference.

6.1 Width

The intercanine diameter increases only slightly in the mandible, and some of these increases in due to the distal tipping of the primary cuspids into the primate space (Figure6) below.

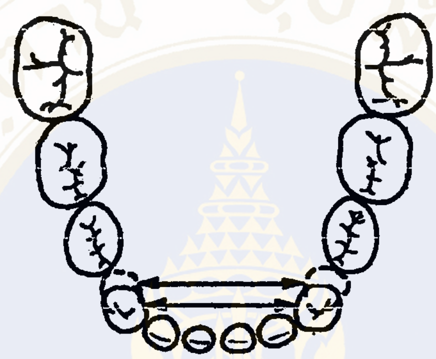

Figure 6 The movement of the primary cuspid distally into the primate spaces with the eruption of the permanent mandibular incisors. Note that if one is measuring the diameter between the primary cuspids, a wider diameter is recorded as they are pushed distally on the divergent arch. (2)

It is important to note the reasons for the rather marked differences in width increase between the two dental arches. The only postnatal mechanism for widening the basal bony width of the mandible is that of deposition on the lateral borders of the corpus mandibularis. Such deposition occurs, but only in the small amounts, and offers little help for the clinician wishing to widen the mandibular dental arch. The maxilla, in sharp contrast, widens with vertical growth simply because the alveolar processes diverge; therefore, more width increase is seen and more can be procured permanently during treatment (Figure7). Furthermore, the midpalatal suture can be reopened with "palatal splitting" to acquire surprisingly large amounts of actual widening of the maxilla. There is little correlation between dental arch widths and any facial width measurements; therefore, knowledge of the latter is of no real use in planning orthodontic treatment.

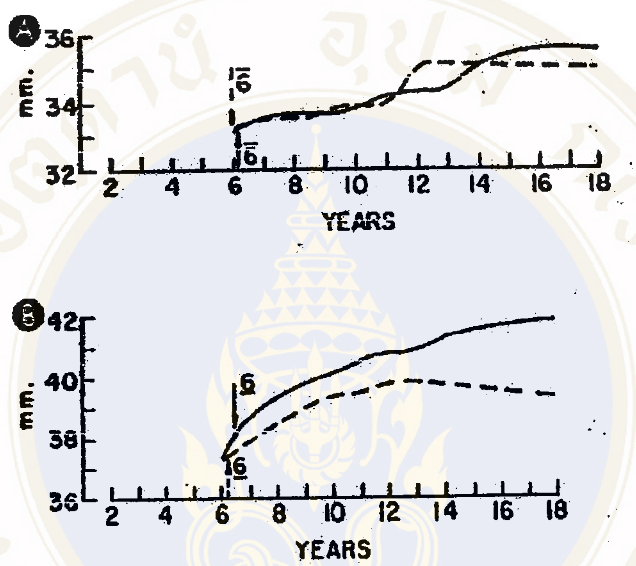

Figure7 A, the stability of the mandibular first permanent molar diameter. Note that only slight changes in this diameter occur and those are concomitant with the eruption of the second permanent molar, which presumably frees the maxillary first permanent molar region. The gradual and significant increases in maxillary first permanent molar region. The gradual and significant increases in maxillary molar width eventually are countered by the mesial drifting of the first permanent molar to a narrower diameter.

6.2 Length

Dental arch is measured at the midline from a point midway between the central incisors to a tangent touching the distal surfaces of the second primary molars or second premolars (Figure5). Although often measured and reported it does not have the clinical importance of the circumference, and any changes in arch length are but coarse reflections of changes in perimeter. Sometimes one-half the circumference is referred of as arch length.

6.3 Circumference or Perimeter

The essential part of the dental arch dimension is arch circumference or perimeter, which usually is measured from the distal surface of the second primary molar (or mesial surface of the first permanent molar) around the arch over the contact points and incisal edges in a smoothed curve to the distal surface of the second primary molar (or first permanent molar) of the opposite side (Figure5). A wide range of variability is seen in circumferential increments and the mandibular and maxillary perimeters behave a bit differently; therefore, they will be discussed separately.

Both Fisk and Moorrees (2) report a mean reduction in mandibular arch circumference during the transitional and early adolescent dentition of about 5 mm. Such a large decrease is due to

- The late mesial shift of the first permanent molars as the "leeway space" is pre-empted,
- The mesial drifting tendency of the posterior teeth throughout all of life
- slight amounts of interproximal wear of the teeth
- The lingual positioning of the incisors due to differential mandibulomaxillary growth.

The mandibular permanent incisors are thicker labiolingually than the predecessors, yet they usually occupy the same position in the arch. When the mandibular permanent incisors become tipped labially, the arch perimeter usually decreases greatly in both sexes during the transitional and young adult period.

Maxillary arch perimeter, in contrast, typically increases slightly, although it has about an equal chance to either increase or decrease (Figure 8). The very marked difference in angulation of the maxillary permanent incisors, as compared to the primary (Figure 9) and the greater increases in width probably account for the tendency to preserve the circumference in the upper jaw even though the permanent molars are drifting mesially.

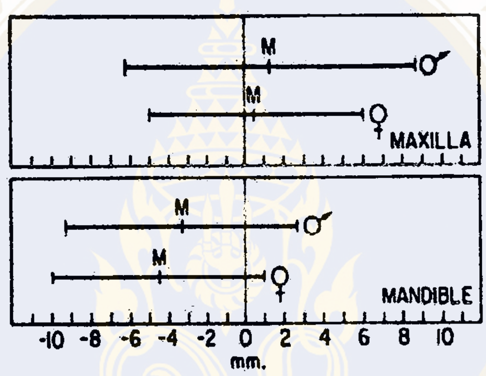

Figure 8 Changes in the arch perimeters from the primary to the early permanent dentition. Note the large decreases in the mandibular arch perimeter and the relatively stable maxillary arch perimeter. (2)

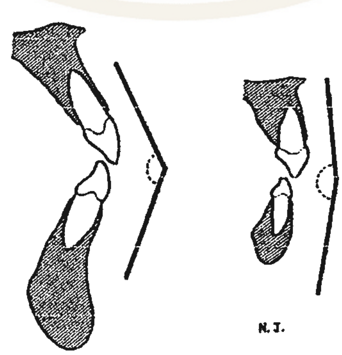

Figure 9 A comparison of the angulation of the permanent and primary incisors (2)

7. Dimensional changes during orthodontic therapy

Figure 10 summarizes the normal growth changes in both dental arches and compares such changes with changes that can be brought about by orthodontic therapy. It is important to note very carefully that it is far easier to increase dental arch width and length in the maxilla that it is in the mandible. In fact, it is relatively simple to increase the maxillary dental arch width and length, difficult to increase and retain the mandibular dental arch width and nearly impossible to move mandibular molars distally significantly to increase the perimeter and hold that increase. The effects of orthodontic treatment on dental arch dimensions are not to be confused with the effects of orthodontic treatment on craniofacial skeletal dimensions. (6)

	PRIMARY DENTITION		MIXED DENTITION	
MANDIBLE	GROWTH	TREATMENT	GROWTH	TREATMENT
WIDTH	O	+	O	O
PERIMETER	O	O	— —	O
MAXILLA				
WIDTH	+	+	+	++
PERIMETER	O	+	O	++

O Same
— — Decreases Greatly
+ Mild Increase Occurs or can be Obtained
++ Significant Increase Occurs or can be Obtained

Figure 10 Normal growth comparison (2)

II. Universal Serial Bus System

1. The USB System Description

The Universal Serial Bus [USB] is a cable bus that supports data exchange between a host computer and a wide range of simultaneously accessible peripherals. The attached peripherals share USB bandwidth through a hostsheduled, token-based protocol. The bus allows peripherals to be attached, configured, used and detached while the host and other peripherals are in operation.

2. Goal of the Universal Serial Bus

The USB is specified to be an industry-standard extension to the PC architecture with a focus on PC peripherals that enable consumer and business applications. The following criteria were applied in defining the architecture for the USB.

- Ease of use for PC peripheral expansion
- Low-cost solution that supports transfer rate up to 480 Mb/s
- Full support for real time data for voice, audio and video
- Protocol flexibility for mixed mode isochronus data transfer and asynchronous massaging
- Integration in commodity device technology
- Comprehension of various PC configurations and forms factors
- Provision of the standard interface capable of quick diffusion in to product
- Enabling new classes of devices that augment the PC's capability
- Full backward compatibility of USB for devices build to previous version of the specification.

3. The universal base system

A USB system is described by three definition areas:

3.1 USB interconnect

The USB interconnect is the manner in which USB devices are connected to and communicate with the host. This includes the following:

- Bus Topology: Connection model between USB devices and the host.
- Inter-layer Relationships: In terms of a capability stack, the USB tasks that are performed at each layer in the system.
- Data Flow Models: The manner in which data moves in the system over the USB between producers and consumers.
- USB Schedule: The USB provides a shared interconnect. Access to the interconnect is scheduled in order to support isochronous data transfers and to eliminate arbitration overhead.

3.2 USB devices

USB devices are one of the following:

- Hubs, which provide additional attachment points to the USB
- Functions, which provide capabilities to the system such as an ISDN connection, a digital joystick, or speakers

USB devices present a standard USB interface in terms of the following:

- Their comprehension of the USB protocol
- Their response to standard USB operations, such as configuration and reset

- Their standard capability descriptive information

Lists below are the main USB systems:

- **Electrical System**

The USB transfers signal and power over a four-wire cable, shown in Figure below. The signaling occurs over two wires on each point to point segment.

There are three data rates:

- The USB high-speed signaling bit rate is 480 Mb/s.
- The USB full-speed signaling bit rate is 12 Mb/s.
- A limited capability low-speed signaling mode is also defined at 1.5 Mb/s.

USB 2.0 host controllers and hubs provide capabilities so that full-speed and low-speed data can be transmitted at high speed between the host controller and the hub, but transmitted between the hub and the device at full-speed or low-speed. This capability minimizes the impact that full-speed and low-speed devices have upon the bandwidth available for high-speed devices.

The low-speed mode is defined to support a limited number of low-bandwidth devices, such as mice, because more general use would degrade bus utilization.

The clock is transmitted, encoded along with the differential data. The clock-encoding scheme is NRZI with bit stuffing to ensure adequate transitions. A SYNC field precedes each packet to allow the receiver(s) to synchronize their bit recovery clocks.

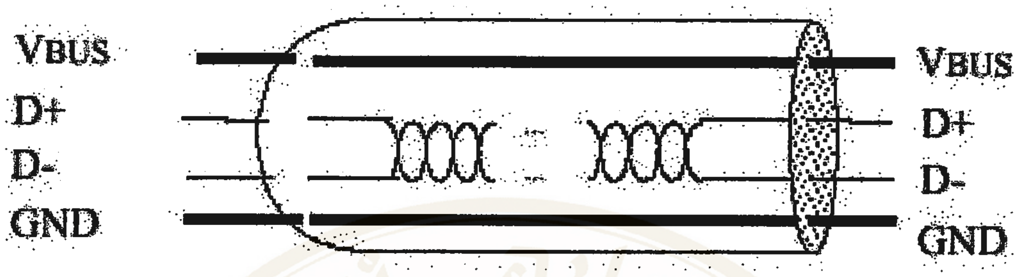

Figure 11 The USB cords

- **Power System**

The specification covers two aspects of power:

- Power distribution over the USB deals with the issues of how USB devices consume power provided by the host over the USB.

- Power management deals with how the USB System Software and devices fit into the host-based power management system.

➢ *Power Distribution*

Each USB segment provides a limited amount of power over the cable. The host supplies power for use by USB devices that are directly connected. In addition, any USB device may have its own power supply. USB devices that rely totally on power from the cable are called bus-powered devices. In contrast, those that have an alternate source of power are called self-powered devices. A hub also supplies power for its connected USB devices. The architecture permits bus-powered hubs within certain constraints of topology.

➢ *Power Management*

A USB host may have a power management system that is independent of the USB. The USB System Software interacts with the host power management system to handle system power events such as suspend or resume. Additionally, USB devices typically implement additional power management features that allow them to be power managed by system software.

The power distribution and power management features of the USB allow it to be designed into power sensitive systems such as battery-based notebook computers.

➢ Device Characterizations

All USB devices are accessed by a USB address that is assigned when the device is attached and enumerated. Each USB device additionally supports one or more pipes through which the host may communicate with the device. All USB devices must support a specially designated pipe at end point zero to which the USB device's USB controlled pipe will be attached. All USB devices support a common access mechanism for accessing information through control pipe.

Associated with the control pipe at end point zero is the information required to completely describe the USB device. This information falls into the following categories:

- Standard: This is information whose definition is common to all USB devices and includes items such as vendor identification, device class, and power management capability. Device, configuration, interface, and endpoint descriptions carry configuration-related information about the device.

- Class: The definition of this information varies, depending on the device class of the USB device.

- USB Vendor: The vendor of the USB device is free to put any information desired here. The format, however, is not determined by this specification.

Additionally, each USB device carries USB control and status information.

- USB Host: Hardware and Software

The USB host interacts with USB devices through the Host Controller. The host is responsible for the following:

- Detecting the attachment and removal of USB devices.
- Managing control flow between the host and USB devices
- Managing data flow between the host and USB devices
- Providing power to attached USB devices

The USB System Software on the host manages interactions between USB devices and host-based device software. There are five areas of interactions between the USB System Software and device software:

- Device enumeration and configuration
- Isochronous data transfers
- Asynchronous data transfers
- Power management
- Device and bus management information

III. IMAGING GEOMETRY

1. Basic Transformations

The material in this section deals with a development of a unified representation for problems such as image rotation, scaling, and translation.

All transformations are express in a three-dimensional (3-D) Cartesian coordinate system in which a point has coordinated denoted (X, Y, Z). In cases involving 2D images, we adhere to our previous convention of lowercase representation (x, y, z) to denote the coordinates of the pixel. Referring to (X, Y, Z) as the *world coordinate* of a point is common terminology.

1.1 Translation

Suppose that the task is to translate a point with coordinates (X, Y, Z) to a new location by using displacements (Xo, Yo, Zo). The translation is easily accomplished by using equation 2-1 to 2-3.

$$X^* = X + X_o \qquad [2\text{-}1]$$

$$Y^* = Y + Y_o \qquad [2\text{-}2]$$

$$Z^* = Z + Z_o \qquad [2\text{-}3]$$

Where (X*, Y*, Z*) are the coordinates of the new point. Above equation may be expressed in matrix form by writing

$$\begin{pmatrix} X^* \\ Y^* \\ Z^* \end{pmatrix} = \begin{pmatrix} 1 & 0 & 0 & X^* \\ 0 & 1 & 0 & Y^* \\ 0 & 0 & 1 & Z^* \end{pmatrix} \qquad [2\text{-}4]$$

It is often useful to concentrate several transformations to produce a composite result, such as translation, followed by scaling and then rotation. The use of square matrices simplifies the notational representation of this process considerably. With this can be written in equation 2-5 as follows:

$$\begin{pmatrix} X^* \\ Y^* \\ Z^* \\ 1 \end{pmatrix} = \begin{pmatrix} 1 & 0 & 0 & Xo \\ 0 & 1 & 0 & Yo \\ 0 & 0 & 1 & Zo \\ 0 & 0 & 0 & 1 \end{pmatrix} * \begin{pmatrix} X \\ Y \\ Z \\ 1 \end{pmatrix} \qquad [2\text{-}5]$$

In terms of the values of X*, Y* and Z*, Eqs. 2-4 and Eqs. 2-5 are equivalent. Throughout this section, we use the unified matrix representation

$$V^* = Av \qquad [2\text{-}6]$$

Where A is a 4*4 transformation matrix, v is the column vector containing the original coordinates,

$$v = \begin{pmatrix} X \\ Y \\ Z \\ 1 \end{pmatrix} \qquad [2\text{-}7]$$

And v* is a column vector whose components are the transformed coordinates

$$v^* = \begin{pmatrix} X^* \\ Y^* \\ Z^* \\ 1 \end{pmatrix} \qquad [2\text{-}8]$$

With this notation, the matrix used for translation is

$$T = \begin{pmatrix} 1 & 0 & 0 & Xo \\ 0 & 1 & 0 & Yo \\ 0 & 0 & 1 & Zo \\ 0 & 0 & 0 & 1 \end{pmatrix} \qquad [\,2\text{-}9\,]$$

And the translation process is accomplished by using Eq. 2-6, so that v*= Tv

1.2 Scaling

Scaling by factors Sx, Sy, and Sz along the X, Y, and Z axes is given by the transformation matrix

$$S = \begin{pmatrix} Sx & 0 & 0 & 0 \\ 0 & Sy & 0 & 0 \\ 0 & 0 & Sz & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix} \qquad [\,2\text{-}10\,]$$

1.3 Rotation

The transformation used for 3-D rotation are inherently more complex than the transformations discussed thus far. The simplest form of these transformations is for rotation of a point about the coordinate axes. To rotate a point about another arbitrary point in space requires three transformations: the first translates the arbitrary point to the origin, the second performs the rotation, and the third translates the point back to its original position. The rotation of a point about the Z coordinate axis by an angle is achieved by using the transformation:

$$R_\theta = \begin{pmatrix} \cos\theta & \sin\theta & 0 & 0 \\ -\sin\theta & \cos\theta & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix} \qquad [\,2\text{-}11\,]$$

The rotation angle α is measured clockwise when looking at the origin from a point to the +Z axis. This transformation affects only the values of X and Y coordinates.

Rotation of a point about the X axis by an angle α is performed by using the transformation

$$R_\alpha = \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & \cos\alpha & \sin\alpha & 0 \\ 0 & -\sin\alpha & \cos\alpha & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix} \quad [2\text{-}12]$$

Finally, rotation of a point about the Y axis by an angleβ is achieved by using the transformation

$$R_\beta = \begin{pmatrix} \cos\beta & 0 & -\sin\beta & 0 \\ 0 & 1 & 0 & 0 \\ \sin\beta & 0 & \cos\beta & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix} \quad [2\text{-}13]$$

1.4 Concatenation and inverse transformations

The application of several transformations can be represented by a single 4*4 transformation matrix. For example, translation, scaling, and rotation about the Z axis of a point v is given by

$$v^* = (s(Tv)) = Av \quad [2\text{-}14]$$

Where A is the 4*4 matrix $A = R_\theta ST$. These matrices generally do not commute, so the order of application is important.

Although the discussion thus far has been limited to transformation of a single point, the same ideas extend to transforming a set of *m* points simultaneously by using a single transformation. With the reference to Eq.2-7, let $v_1, v_2, \ldots, v_m$ represent the coordinates of *m* points. For a 4×m matrix V whose columns are these column vectors, the simultaneous transformation of all these points by a 4×4 transformation matrix A is given by

$$V^* = AV \qquad [2\text{-}15]$$

The resulting matrix V^* is 4×m. Its *i*th column, v_i^*, contains the coordinates of the transformed point corresponding to v_i.

Many of the transformations discussed above have inverse matrices that perform the opposite transformation and can be obtained be inspection. For example, the inverse translation matrix is

$$T^{-1} = \begin{pmatrix} 1 & 0 & 0 & -X_o \\ 0 & 1 & 0 & -Y_o \\ 0 & 0 & 1 & -Z_o \\ 0 & 0 & 0 & 1 \end{pmatrix} \qquad [2\text{-}16]$$

Similarly, the inverse rotation matrix R_θ^{-1} is

$$R_\theta = \begin{pmatrix} \cos(-\theta) & \sin(-\theta) & 0 & 0 \\ -\sin(-\theta) & \cos(-\theta) & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix} \qquad [2\text{-}17]$$

The inverses of more complex transformation matrices are usually obtained by numerical techniques.

1.5 Perspective Transformations

A perspective transformation (also called an imaging transformation) projects 3-D points onto a plane. Perspective transformations play a central role in image processing because they provide an approximation to the manner in which an image is formed by viewing a 3-D world.

The camera coordinate system (x, y, z) has the image coincident with the *xy* plane and the optical axis (established by the center of the lens) along the z-axis. Thus the center of the image plane is at the origin, and the center of the lens is at coordinates (0, 0, λ). If the camera is in focus for distant objects, λ is the *focal length* of the lens. Here the assumption is that the camera coordinate system is aligned with the world coordinate system (X, Y, Z).

Let (X, Y, Z) be the world coordinates of any point in a 3-D scene. We assume throughout the following discussion that $Z > \lambda$; that is, all points of interest lie in front of the lens. The first step is to obtain a relationship that gives the coordinates (x, y) of the projection of the point (X, Y, Z) onto the image plane. This is easily accomplished by the use of similar triangles. (9)

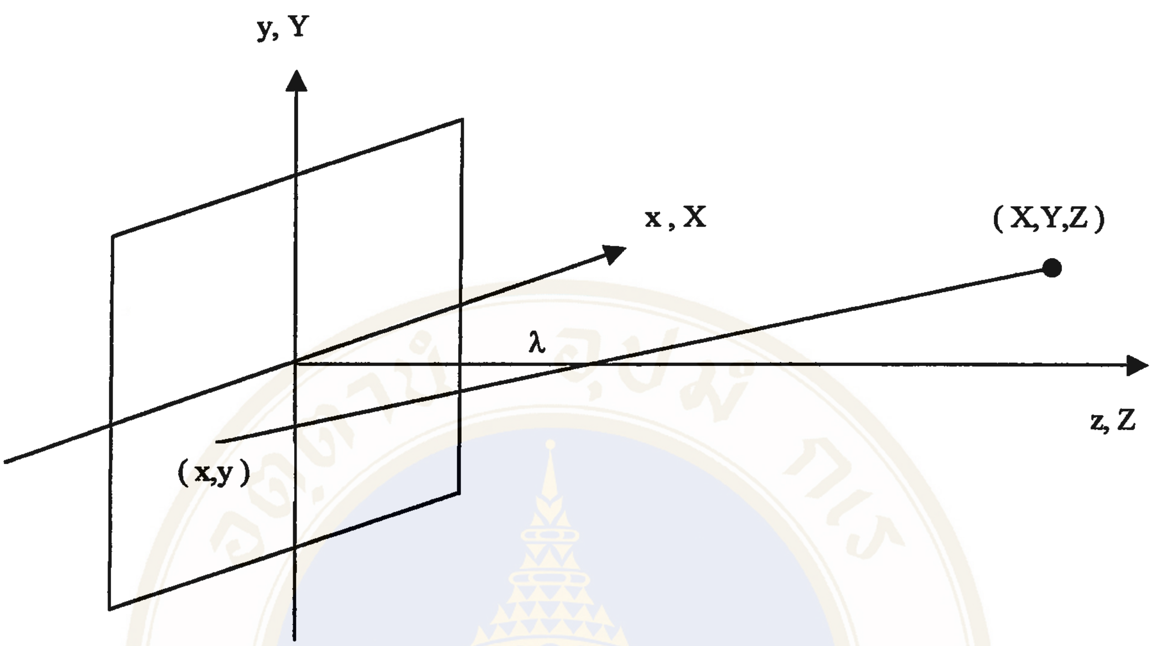

Figure 12 Basic model of imaging process. The camera coordinate system (x, y, z) is aligned with the world coordinate system (X, Y, Z). (9)

$$\frac{x}{\lambda} = -\frac{X}{Z-\lambda} = \frac{X}{\lambda - Z} \qquad [\,2\text{-}18\,]$$

and

$$\frac{y}{\lambda} = -\frac{Y}{Z-\lambda} = \frac{Y}{\lambda - Z} \qquad [\,2\text{-}19\,]$$

Where the negative sign in the front of X and Y indicate that image points are actually inverted.

The image-plane coordinates of the projected 3-D point follow directly from Eqs.2-18 and 2-19:

$$x = \frac{\lambda X}{\lambda - Z} \quad [\text{ 2-20 }]$$

and

$$y = \frac{\lambda Y}{\lambda - Z} \quad [\text{ 2-21 }]$$

These equation are nonlinear because they involve division by the variable Z. Although we could use them directly as shown, it is often convenient to express them in linear matrix form for rotation, translation, and scaling. This is easily accomplished by using homogeneous coordinates. (10)

The homogeneous coordinates of a point with Cartesian coordinates (X, Y, Z) are defined as (kX, kY, kZ, k), where k is an arbitrary, non zero constant. Clearly, conversion of homogeneous coordinates back to Cartesian coordinates is accomplished by dividing the first three homogeneous coordinates by the fourth. A point in the Cartesian world coordinate system may be expressed in vector form as and its homogeneous counterpart is given by

$$w = \begin{pmatrix} X \\ Y \\ Z \end{pmatrix} \quad [\text{ 2-22 }]$$

If we define the *perspective transformation matrix* as

$$P = \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & \frac{-1}{\lambda} & 1 \end{pmatrix} \quad [\text{ 2-23 }]$$

The product $\mathbf{Pw_h}$ yields a vector denoted $\mathbf{c}_h$:

$$\mathbf{c}_h = \mathbf{Pw_h} \qquad [\,2\text{-}24\,]$$

$$= \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & \frac{-1}{\lambda} & 1 \end{pmatrix} \begin{pmatrix} kX \\ kY \\ kZ \\ k \end{pmatrix}$$

$$= \begin{pmatrix} kX \\ kY \\ kZ \\ \frac{-kZ}{\lambda} + k \end{pmatrix}$$

The elements of $\mathbf{c}_h$ are the camera coordinates in homogeneous form. As indicated, those coordinates can be converted to Cartesian form by dividing each of the first three components of $\mathbf{c}_h$ by the fourth. Thus the Cartesian coordinates of any point in the camera coordinate system are given in vector form by

$$c = \begin{pmatrix} x \\ y \\ z \end{pmatrix} = \begin{pmatrix} \frac{\lambda X}{\lambda - Z} \\ \frac{\lambda Y}{\lambda - Z} \\ \frac{\lambda Z}{\lambda - Z} \end{pmatrix} \qquad [\,2\text{-}25\,]$$

The first two components of **c** are the (x,y) coordinates in the image plane of a projected 3-D point (X, Y, Z), as shown earlier in Eqs. 2-20 and 2-21. The third component is of no interest in terms of the model. As shown next, this component acts as a free variable in the inverse perspective transformation.

The inverse perspective transformation maps an image point back into 3-D. Thus Eq. 2-24.

$$w_h = P^{-1}c_h \qquad [\,2\text{-}26\,]$$

Where P^{-1} is

$$P^{-1} = \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & \frac{1}{\lambda} & 1 \end{pmatrix} \qquad [\,2\text{-}27\,]$$

Suppose that an image point has coordinates (x_o, y_o, 0), where the 0 in the z location simply indicates that the image plane is located at z = 0. This point may be expressed in homogeneous vector form as

$$c_h = \begin{pmatrix} kx_o \\ ky_o \\ 0 \\ k \end{pmatrix} \qquad [\,2\text{-}28\,]$$

Application of Eq.2-26 yields the homogeneous world coordinate vector

$$w_h = \begin{pmatrix} kx_o \\ ky_o \\ 0 \\ k \end{pmatrix} \qquad [\,2\text{-}29\,]$$

or, in Cartesian coordinates,

$$w = \begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} x_0 \\ y_0 \\ 0 \end{bmatrix} \qquad [\,2\text{-}30\,]$$

The result obviously is unexpected because it gives Z = 0 for *any* 3-D point. The problem here is caused by mapping a 3-D scene onto the image plane, which is a many to one transformation. The image point (x_o, y_o) corresponds to the set of collinear 3-D points that lie on the line passing through (x_o, y_o, 0) and (0, 0, λ). The equations of this line in the world coordinate system come from Eqs. 2-20 and 2-21; that is,

$$X = \frac{x_0}{\lambda}(\lambda - Z) \qquad [2\text{-}31]$$

and

$$Y = \frac{y_0}{\lambda}(\lambda - Z) \qquad [2\text{-}32]$$

Equations 2-31 and 2-32 show that unless something is known about the 3-D point that generated an image point (for example, its Z coordinate), it is not possible to completely recover the 3-D point from its image. This observation, which certainly is not unexpected, can be used to formulate the inverse perspective transformation by using the z component of $\mathbf{c}_h$ as a free variable, instead of 0. Thus by letting

$$c_h = \begin{matrix} kx_o \\ ky_o \\ kz_o \\ k \end{matrix} \qquad [2\text{-}33]$$

it follows from above equation that

$$w_h = \begin{pmatrix} kx_0 \\ ky_0 \\ kz \\ \dfrac{kz}{\lambda} + k \end{pmatrix} \qquad [\,2\text{-}34\,]$$

which upon conversion to Cartesian coordinates gives

$$w = \begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} \dfrac{\lambda x_0}{\lambda + z} \\ \dfrac{\lambda y_0}{\lambda + z} \\ \dfrac{\lambda z}{\lambda + z} \end{bmatrix} \qquad [\,2\text{-}35\,]$$

In other words, treating z as a free variable yields the equations

$$X = \frac{x_o}{\lambda}(\lambda - Z) \qquad [\,2\text{-}36\,]$$

$$Y = \frac{y_0}{\lambda}(\lambda - Z) \qquad [\,2\text{-}37\,]$$

Solving for z in terms of Z in the last equation and substituting in the first two expressions yields

$$X = \frac{\lambda x_0}{\lambda + z}$$
$$Y = \frac{\lambda y_0}{\lambda + z} \qquad [\,2\text{-}38]$$
$$Z = \frac{\lambda z}{\lambda + z}$$

which agrees with the observation that recovering a 3-D point from its image by means of the inverse perspective transformation requires knowledge of at least one of the world coordinates of the point. (11)

2 Camera model

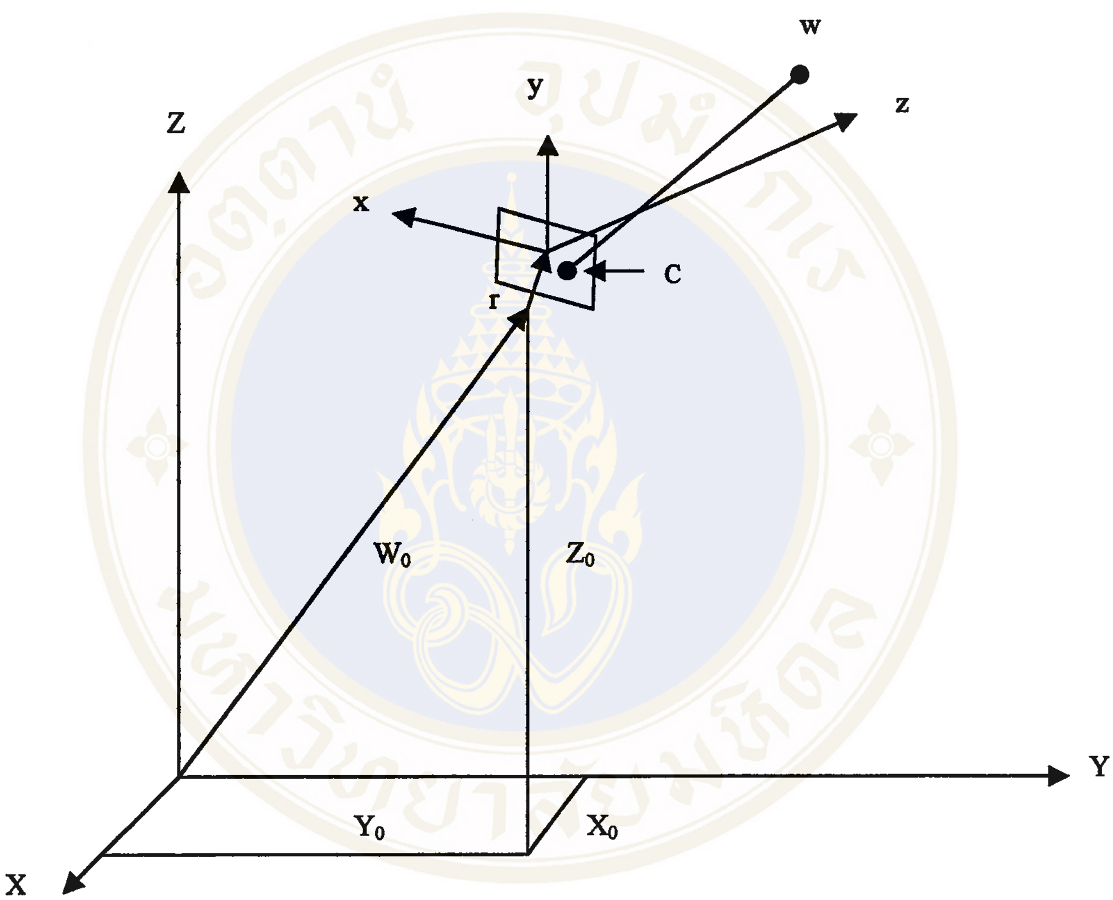

Figure 13 Imaging geometry with two coordinate systems. (9)

Figure 13 show a world coordinate system (X, Y, Z) used to locate both the camera and 3-D points (denoted by **w**). Figure 13 also shows the camera coordinate system (x, y, z) and image points (denoted by **c**). The assumption is that the camera is mounted on a gimbal, which allows pan though an angle θ and tilt though angle α. Here, *pan* is the angle between the x and X axes, and tilt is the angle between the z and Z axes. The offset of the center of the gimbal from the origin of the world coordinate system is denoted by w_o, and the offset of the center of the imaging plane with respect to the gimbal center is denoted by vector **r**, with components (r_1, r_2, r_3).

The concepts developed in above sections provide all the necessary tools to derive a camera model based on the geometric arrangement. The approach is to bring the camera and world coordinate systems into alignment by applying a set of transformations. After doing so, we simply apply the perspective transformation of previous section to obtain the image-plane coordinates for nay world point. In other words, we first reduce the problem to the geometric arrangement shown in Figure 12 before applying the perspective transformation.

Suppose that, initially, the camera was in *normal position*, in the sense that the gimbal center and origin of the image plane were at the origin of the world coordinate system, and all axes were aligned. The geometric arrangement of Figure 13 may then be achieved in several ways.

1. Displacement of the gimbal center from the origin
2. Pan of the x axis
3. Tilt of the z axis
4. Displacement of the image plane with respect to the gimbal center

Obviously, the sequence of these mechanical steps does not affect the world points because the set of points seem by the camera after it was moved from normal position is quite different. However, applying exactly the same sequence of steps to all world points can achieve normal position again. A camera in normal position satisfies the arrangement of Figure 12 for application of the perspective transformation. Thus the problem is reduced to applying to every world point a set of transformations that correspond to the steps listed earlier.

Translation of the origin of the world coordinate system to the location of the gimbal center is accomplished by using the transformation matrix.

$$G = \begin{matrix} 1 & 0 & 0 & -X_0 \\ 0 & 1 & 0 & -Y_0 \\ 0 & 0 & 1 & -Z_0 \\ 0 & 0 & 0 & 1 \end{matrix} \qquad [2\text{-}39]$$

In the other words, a homogeneous world point $\mathbf{w}_h$ that was at coordinates (X_0, Y_0, Z_0) is at the origin of the new coordinate system after the transformation $\mathbf{Gw}_h$.

The pan angle is measured between the x and X axes. In normal position, these two axes are aligned, In order to pan the x axis though the desired angle, we simply rotate it by θ. The rotation is with respect to the z axis and is accomplished by using the transformation matrix $\mathbf{R}_\theta$ of Eq. 2-11. In other words, application of this matrix to all points (including the point $\mathbf{Gw}_h$) effectively rotates the x axis to the desired location. Angles are considered positive when points are rotated clockwise, which implies a counterclockwise rotation of the camera about the z axis. The unrotated (0°) position corresponds to the case when the x and X axes are aligned.

At this point the z and Z axes are still aligned. Since tilt is the angle between these two axes, we tilt the camera an angle α by rotating the z axis by α. The rotation is with respect to the x axis and is accomplished by applying the transformation matrix $\mathbf{R}_\alpha$ of Eq. 2-12 to all points (including the point $\mathbf{R}_\theta$ $\mathbf{Gw}_h$). Again, a counterclockwise rotation of the camera implies positive angles, and the 0° mark is when the z and Z axes are aligned.

According to the discussion in previous section, the two rotation matrices can be concatenated into a single matrix, $\mathbf{R} = \mathbf{R}_\alpha \mathbf{R}_\theta$. Then, from Eqs.2-11 and 2-12

$$R = \begin{pmatrix} \cos\theta & \sin\theta & 0 & 0 \\ -\sin\theta.\cos\alpha & \cos\theta.\cos\alpha & \sin\alpha & 0 \\ \sin\theta.\sin\alpha & -\cos\theta.\sin\alpha & \cos\alpha & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix} \quad [\,2\text{-}40\,]$$

Finally, displacement of the origin of the image plane by vector **r** is achieved by the transformation matrix.

$$C = \begin{pmatrix} 1 & 0 & 0 & -r_1 \\ 0 & 1 & 0 & -r_2 \\ 0 & 0 & 1 & -r_3 \\ 0 & 0 & 0 & 1 \end{pmatrix} \quad [\,2\text{-}41\,]$$

3 Camera Calibration

Development in this field requires knowledge of the focal length, offsets, and angles of pan and tilt. Although these parameters could be measured directly, determining one or more of the parameters using the camera itself as a measuring device often is more convenient (especially when the camera moves frequently). This requires a set of image points whose world coordinates are known, and the computational procedure used to obtain the camera parameters using these known points often used referred to as *camera calibration*, and the equation for camera calibration is shown in eq. 2-42. (9)

$$\begin{bmatrix} c_{h1} \\ c_{h2} \\ c_{h3} \\ c_{h4} \end{bmatrix} = \begin{bmatrix} a_{11} & a_{12} & a_{13} & a_{14} \\ a_{21} & a_{22} & a_{23} & a_{24} \\ a_{31} & a_{32} & a_{33} & a_{34} \\ a_{41} & a_{42} & a_{43} & a_{44} \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \\ 1 \end{bmatrix} \quad [\,2\text{-}42\,]$$

CHAPTER III

MATERIALS AND METHODS

MATERIALS

In order to complete the project, access to certain resources is required.

1. Hardware Resource

Development of software was done with the use of:

CPU	:	Celeron 488Hz.
RAM	:	At least 64 MB
Hard Disk	:	At least 4 GB
Monitor	:	15" Super VGA Monitor
Peripherals	:	Keyboard, Mouse, Sound Card, Speakers, Microphone, Scanner and DeskJet Printer

2. Software Resource

The software, which is used for developing the system, is given below

Operating System	:	Microsoft Window 98 Thai
Application Tool	:	Microsoft Visual Basic 6.0
Photo Editor	:	Adobe PhotoShop 5.0
Web Browser	:	Microsoft Internet Explorer 5.0

Visual Basic can generate a 32-bit windows application with its pre-modeled generic templates that can be used as a foundation for Windows program. Visual Basic has a very large group of predefined library routines, which is not only found in Microsoft libraries, but in user net groups and the Internet worldwide. In addition, Visual Basic is a more commonly known language, and it is easy to find a Visual Basic programmer. The advantage of programming in Visual Basic is the user-friendly interface and easy programming.

METHODOLOGY

The digital model analysis consists of two major parts, one for digitizing the dental cast information, which must be efficient and easy to use, and the other for performing data calculations, such as tooth size measurements, or dental arc size calculations. The development process can be divided into two main steps as follow:

1. **Collecting Data & Review related documents**
   - To understand the orthodontic treatment in order to integrate it to the project
   - To study the USB port process in order to integrate it to the project
   - To study the programming language, Visual Basic, used to develop the software
   - To understand the 3D measurement method for designing tooth measurement system
2. **System Development**

The system development in this project can be divided into two main parts: the hardware part and the software part.

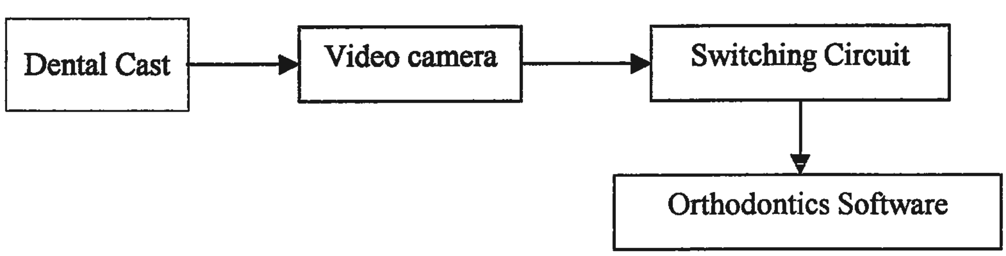

Figure14 System Development

The hardware development

1. Mechanical development

Theoretically, the design concept of measuring device is divided into two major aspects, which are conceptual and detail designs.

1.1 Conceptual design

There are two types of measurement devices, contact and non-contact.

- *Contact type*

This type of design can produce mechanical errors due to surface contact, and surface orientation. Moreover, the material surface also affects the measurement. For example, soft and complex surface can produce difficulties in measurement.

- *Non-contact type*

This type uses the presence of advance technologies, such as optical sensors, laser or digital imaging. The first two technologies can produce a very high precision but the cost is very expensive and the technology development is still unknown. The last choice is digital image technology, which is possible for this research because the cost is not so expensive.

1.2 Detail design

The measurement techniques, which can cover the entire image perspectives, are rotation and non-rotation techniques.

- *Rotation*

Three types of rotation can be performed, including

- rotated object, fixed camera
- rotated camera, fixed object

- rotated camera, rotated object

This technique can capture the image in any view. Moreover, it can also reduce the use of hardware resources. Anyway, this technique still produces high measurement errors due to mechanical movements, especially angular rotation.

- *Non-rotation*

This technique uses higher hardware resources instead of rotating the object. Therefore, higher numbers of cameras are used and all the images acquired from different views are combined using the software. The advantage of this technique is to enormously reduce the errors due to mechanical movements. Anyway, there are still some errors due to the hardware characteristics and the software.

In this research, the non-rotation technique is used, and the system consists of videoconference cameras and structural elements, which are integrated together to acquire the dental cast images from four different views. Video cameras are used for taking picture in this project because they are easily to used and directly controlled by

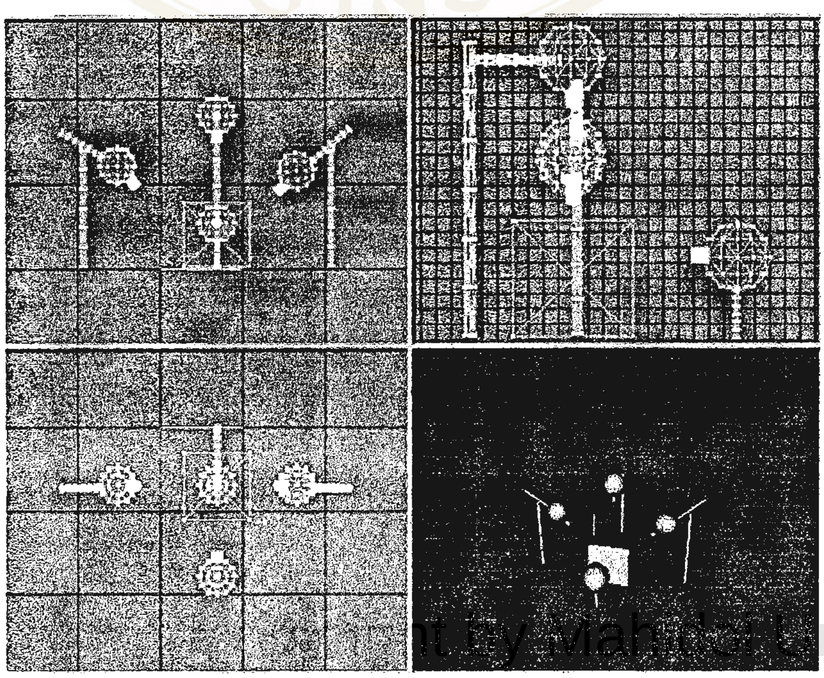

Figure 15 Hardware design

the computer. The specification of the cameras does not require a high sweep rate, but the resolution should be high enough for accurate measurement. The image data and controlled signal are sent via USB port. The USB port has a high transfer rate and can supply the power to any equipment that uses USB port for communications.

There are four cameras used in this project. Since computer main board normally provides 2 USB ports, which are not enough. Therefore, a HUB is used to increase the number of the USB port. All of the video cameras in this system have to be fixed in a right place and the cameras are calibrated with program before using this system. The calibration is obtained by using this system to measure the object that its dimension is known. By this method the scale on the pictures that are taken by the camera is scaled to the right value.

The base of the measuring system is an aluminum plate, which has 5-millimeters thickness. The aluminum plate is drilled for attaching with the camera stands. The stainless camera stand is selected because it is durable and is not corrosive. The reference plate is made up of acrylic, which is attached on the aluminum plate by stainless nuts and bolts. The tip of the stainless rod is milled to match the size of the screw at the button of video cameras. The four cameras are attached on the stand by screwing on the tip of each stand. The camera position is also very important because the dental cast image should fit in the frame to achieve the best image resolution.

2. Electrical development

Table 2 Switching circuit elements

Circuit Components	Functions
Micro controller MCS 8051	Process and Control
ULN 2003	Control the relay
Max 232	Convert from CMOS to TTL
Relay	Connect the signal between cameras

In this part, the system consists of a switching circuit, which is used for selecting a camera to acquire the dental cast image. The reason is because the computer cannot detect multiple cameras of the same model at the same time.

The computer via the COM port controls the circuit. Then, micro controller processes the signal and control each relay set. The relay set consists of two relays for the USB (excluding the USB power line).

The software development

Visual Basic programming was selected as an application tool for this project because it is a widely use program. This program can be applied in many applications such as image processing, database, Internet application. The structure of the program can be written easily and it looks like window so it is friendly used for any user. The program is designed to show four pictures of different views and the dentist who is an expert in the anatomy of tooth has to mark on each tooth that he want to measure in four views and after that the program will calculate the dimension of tooth and display it on screen. All of tooth data will be recorded in the computer and will be used for follow up the treatment result of individual patients. These data is also used for prediction of the mixed dentition analysis in children. The tooth dimension is also required for calculated formula, such as *Bolton Tooth Ratio Analysis.*

The software development for this project assumed the used of the waterfall model, which breaks down software development process into the following six activities:

1. Requirement analysis

This phase deals with determining what the goal of the development is. A set of requirements is defined to obtain the features and capabilities of the system. This stage deals with the purpose not the development. Table 1 below shows the basic requirements of this project.

Table 3 Basic requirements of the software

Needs	**Solutions**
Measurement	All tooth size in mesiodistal axis
Calculation formula	Bolton ratio analysis Kitti and Sinepan formula
Graphic user interface	Write for Windows system on PC
Ease of Use	Simple user interface
Easy manipulation	Simple interface to powerful algorithms
Reusability	Code written with modularity

2. System design

After the requirements are defined, they are translated to design a system that meets the requirements. This process involves transforming the requirements into a solution. The user interface can be divided into four main windows as follows.

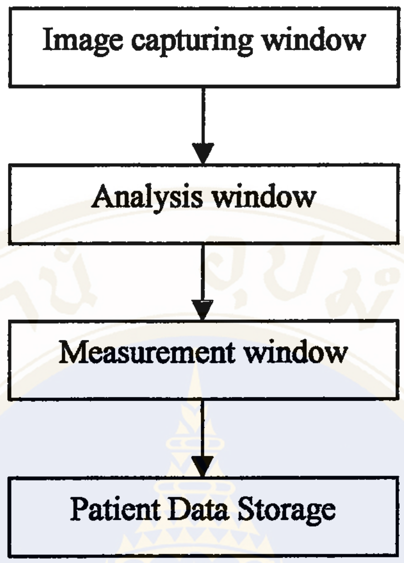

Figure 16 System Design

- **Image capturing window**

This window is used to acquire the dental cast image from the videoconference camera. After obtaining all the images, the tooth size is obtained in the measurement window.

- **Measurement window**

This window allows the user to measure the tooth size, and dental arch curve. Then all the data are displayed in the analysis window. A grid selection also allows user to detect the tooth symmetry.

The measurement part is divided into two parts. The first part calculates the correct displacement that users select on the images. This process use the data at least two views to convert the coordinates on the pictures to the real coordinate that base on the x y and z-axis. The other part is the calculation of orthodontic formula.

There are many formulae in orthodontic that are used in treatment plan. For example, Bolton analysis formula is used for calculating the occlusion relationship.

- **Analysis window**

After obtaining all the information from the measurement window, the program calculates the tooth ratio, dental arch size and other required. This window summarizes all the tooth size, which is measured from the previous window. There are also two types of formula displayed on the screen. The first one is Bolton formula, which requires twelve-tooth size as input data. The second formula is Kitti-Sinepan formula, which requires four-tooth size as input data.

- **Patient data storage**

After all the information is obtained, the program stores all these data in the patient database for future access. The storage window allows the user to search and view the required information of the patient.

The database recording is another important feature because it can be used to follow up the treatment. The database is designed to record the patient ID, name, age, date, time and image. The advantages are zero storage costs, immediate retrieval and archiving, no model breakage, digital model backups, no mess and no waste staff time.

3. Program design

This phase concerns with the mechanisms that efficiently implement the solution. The activities of this phase are decomposition of the program into modules, specification of interactions between modules, design of data structures, and design of algorithms.

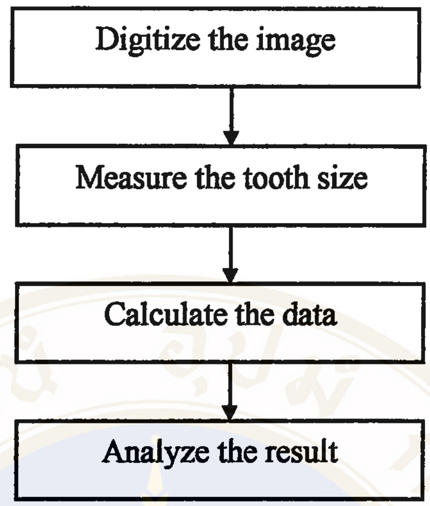

Figure 17 Program design

3.1 Digitizing the dental cast image from the camera using the switching circuit.

3.2 Measuring the tooth size

After the image has been digitized, the program allows user to measure the tooth size by selecting two points from the image. In order to obtain the accurate result, the program must be calibrated by using matrix calculations. Two views must be used for each calculation. The top and front view are used for measuring the anterior tooth size, while the top and side view are used for measuring the posterior tooth size.

- **Point Calibration**

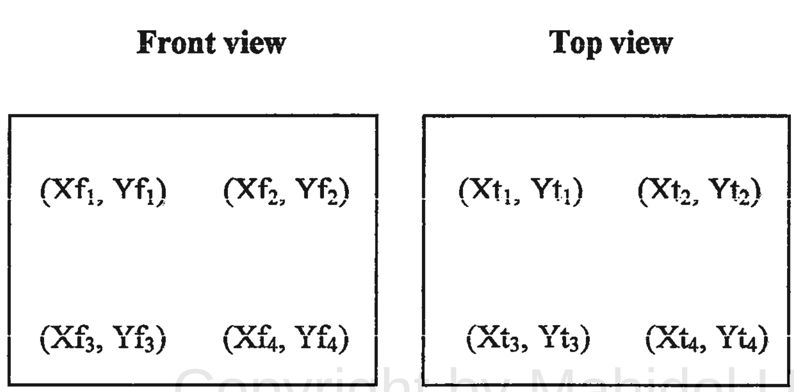

Figure 18 Point Calibration

For anterior tooth size, the calibration process begins by selecting four points from each view of the image. Each point represents the same location in each view. For example, Xf_1 and Xt_1 represent the same location in front and top view respectively. Then, a 4*4 matrix size containing all four coordinates from both views is obtained.

$$F = \begin{bmatrix} Xt_1 & Yt_1 & Xf_1 & Yf_1 \\ Xt_2 & Yt_2 & Xf_2 & Yf_2 \\ Xt_3 & Yt_3 & Xf_3 & Yf_3 \\ Xt_4 & Yt_4 & Xf_4 & Yf_4 \end{bmatrix} \qquad [3\text{-}1]$$

Then, the result is obtained by multiplying this matrix with a coefficient matrix. Though the coefficient is unknown but it can be calculated from the actual values.

$$\begin{bmatrix} Xt_1 & Yt_1 & Xf_1 & Yf_1 \\ Xt_2 & Yt_2 & Xf_2 & Yf_2 \\ Xt_3 & Yt_3 & Xf_3 & Yf_3 \\ Xt_4 & Yt_4 & Xf_4 & Yf_4 \end{bmatrix} * K = \begin{bmatrix} X_1 & Y_1 & Z_1 \\ X_2 & Y_2 & Z_2 \\ X_3 & Y_3 & Z_3 \\ X_4 & Y_4 & Z_4 \end{bmatrix}$$

$$F \quad * K \quad = \quad Y \qquad [3\text{-}2]$$

F = the point matrix of 4*4 matrix size obtained from the program

Y = the result matrix of 4*3 matrix size, which contains the actual coordinates

K = a coefficient of 4*3 matrix size

$$K = Y / F \qquad [3\text{-}3]$$

The process is the same for posterior measurement, but the side view is used for the calibration instead of the front view.

- **Layer slicing**

To obtain a better resolution, the calibration is sliced into layers with 1-cm thickness. The image is sliced into eight layers for anterior calibration, while a 4-layer slicing is used for posterior calibration. Therefore, each layer produces one coefficient matrix.

3.3 Calculating the orthodontic information

3.4 Analyzing the result

4. Program development

Writing program follows the above requirement.

5. Program testing

This phase involves testing of the software including individual modules and the complete system. First, each module must be carefully analyzed to check for errors and inconsistencies. Then, they must be combined to form the complete system. Integration testing ensures that modules interact with each other in the specified way. The most popular approach to integration is bottom-up strategy. That is, modules are combined in increments to provide higher functionality, and each combination is tested for miscommunications. Finally, all modules of the system are included and tested.

6. System testing

This phase concerns with hardware and software testing to check whether it satisfies the entire user specified requirements. It contains four steps:

- Function test: checks whether the system meets its functional requirements.
- Performance test: checks whether the system meets its nonfunctional requirements, such as accuracy and speed.
- Acceptance test: checks the system's overall characteristics against the user's expectations.
- Installation test: checks whether the system meets the requirements when installed in the user's environment.

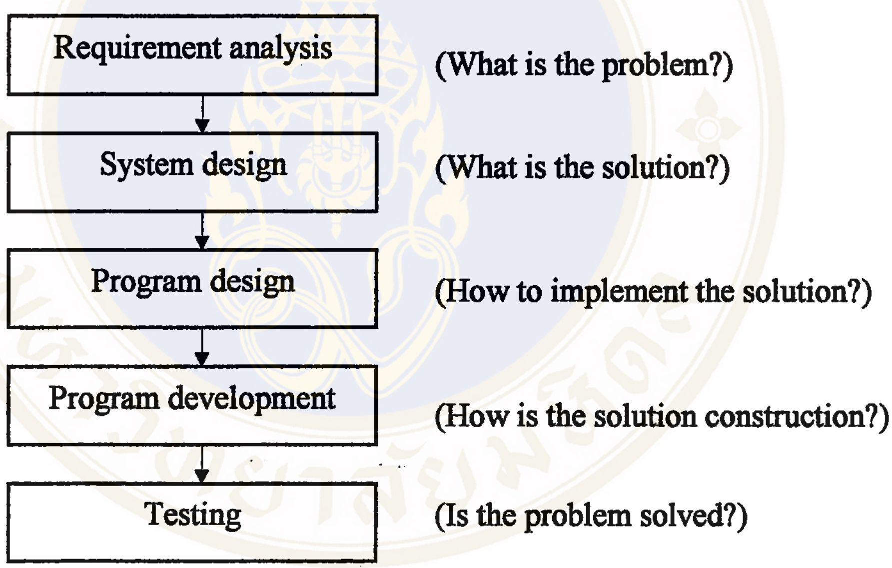

Figure 19 Waterfall model (11)

The development of the software can be divided into 5 main steps, which are requirement analysis, system design, program design, program development, and testing. In requirement analysis, a set of requirements is defined to obtain the features and capabilities of the system. After the requirements are defined, they are translated to design a system that meets the requirements in the step of system design.

CHAPTER IV

RESULT

The result of the program is divided into two main parts, which is reviewed in this section. The first part is the user interface part, which covers the program interface. The other part is the measurement part. This part contains the tested result of the program by measuring the object size from the image and comparing it to the real values.

I. The user interface part

The program contains four window interfaces, which are the main window, measurement, analysis, and database interface.

1. The main window

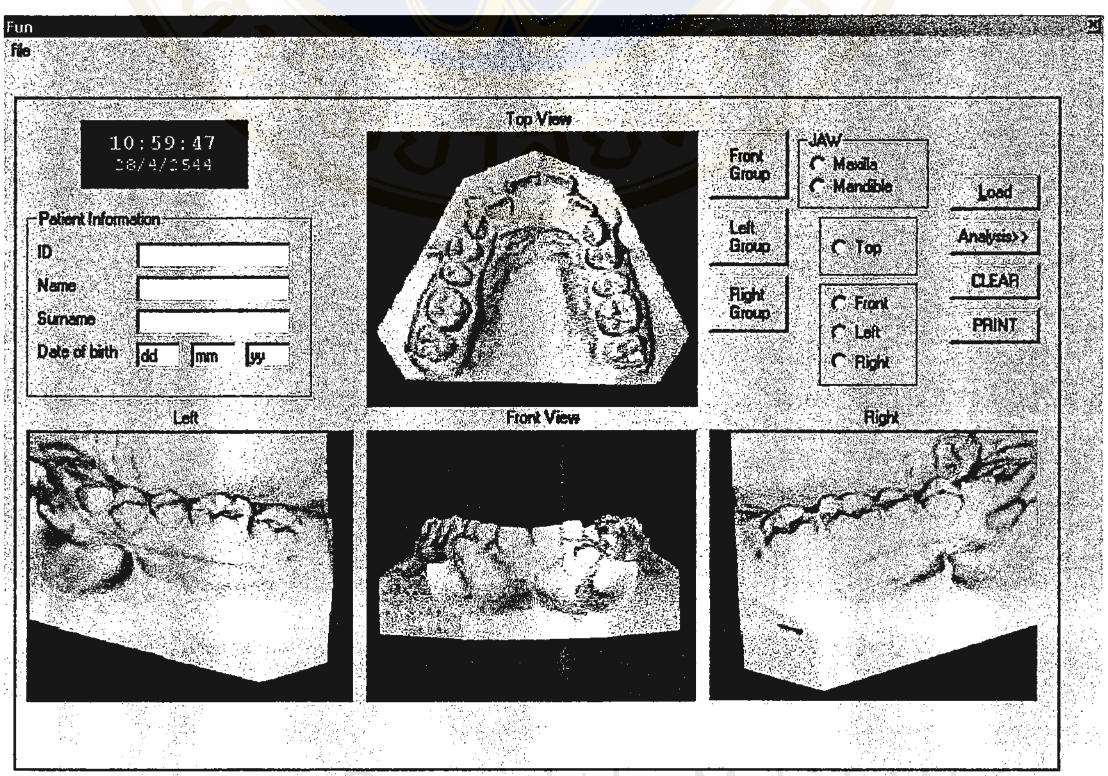

Figure 20 Main Window

After starting the program, the main window is display. The interface can be divided into three main parts. The first part is the patient information area, which locates at the upper-left part of the window. The information includes patient's name, birth date and ID. Then, the next part is the image display area, which locates in the middle part of the window. This area consists of four image windows for displaying the images acquired from all four cameras. The last part is the function menu, which locates at the upper-right part of the window.

- *Load function*

This menu allows user to acquire the image from all four cameras, and displayed them in the display area.

- *Analysis function*

This menu allows user to enter the next window to measure the tooth size for Bolton analysis and Kitti Sinepan formula, which are in the third window.

2. The measurement window

After selecting the 'analysis' menu from the main window, the measurement window is displayed. This window allows users to perform tooth size measurement for further analysis. The tooth size is measured by clicking at the two ends of the width to measure. Then, the width is calculated and displayed.

This window consists of two main parts, which are the image display area and the function menu. The function menu is located at the right part of the window. This part contains functions, which allows users to measure the distance, dental arch length, and angle.

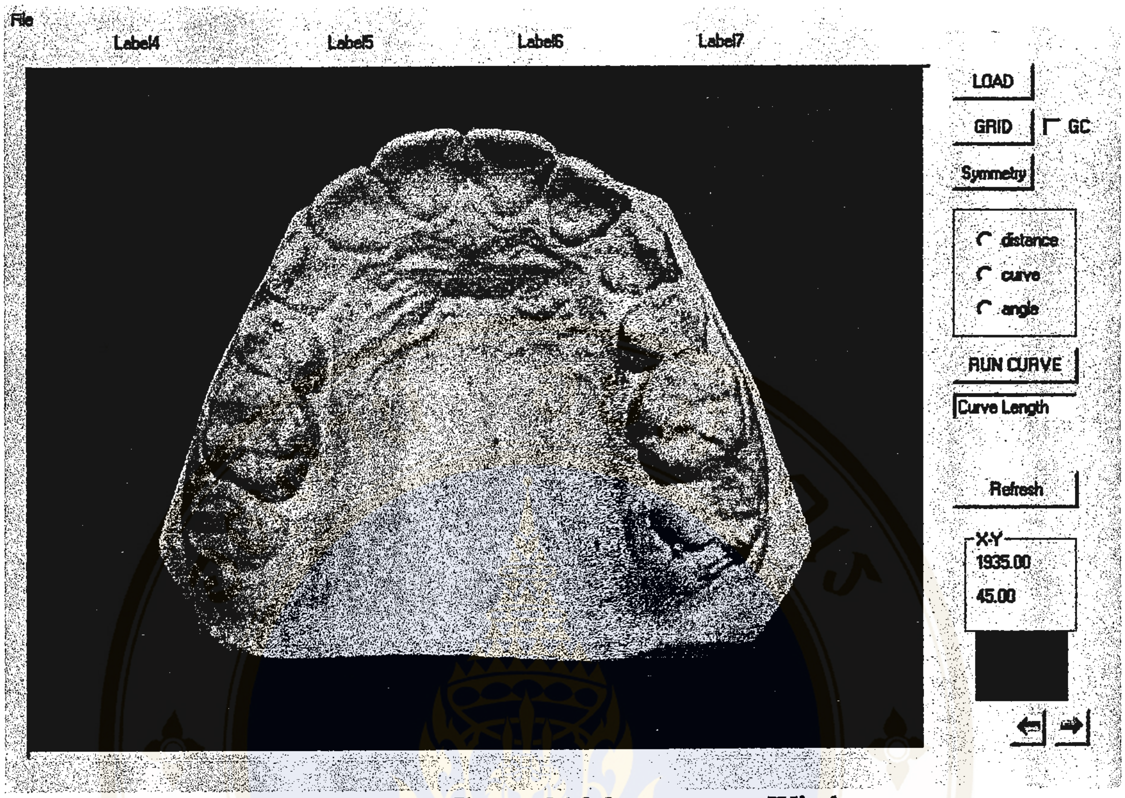

Figure 21 Measurement Window

3. The analysis window

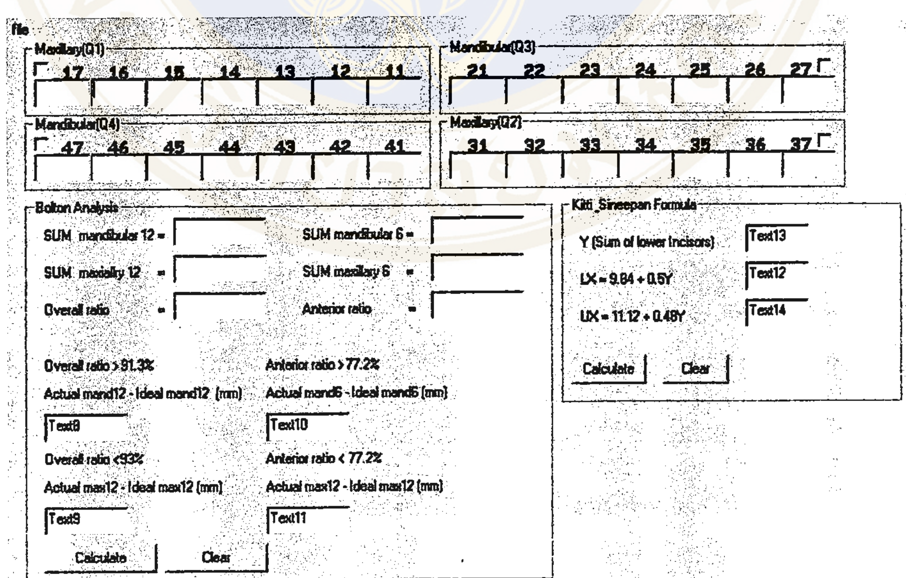

Figure 22 Analysis Window

After the tooth size is collected, the program will display all the measured tooth size in the analysis window. After that, further analysis can be performed. The analysis part is separated into two sections, which are the Bolton analysis and Kitti

Sinnepan formula. The program will calculate the result, including the summation and ratio, and display in the window.

4. The database window

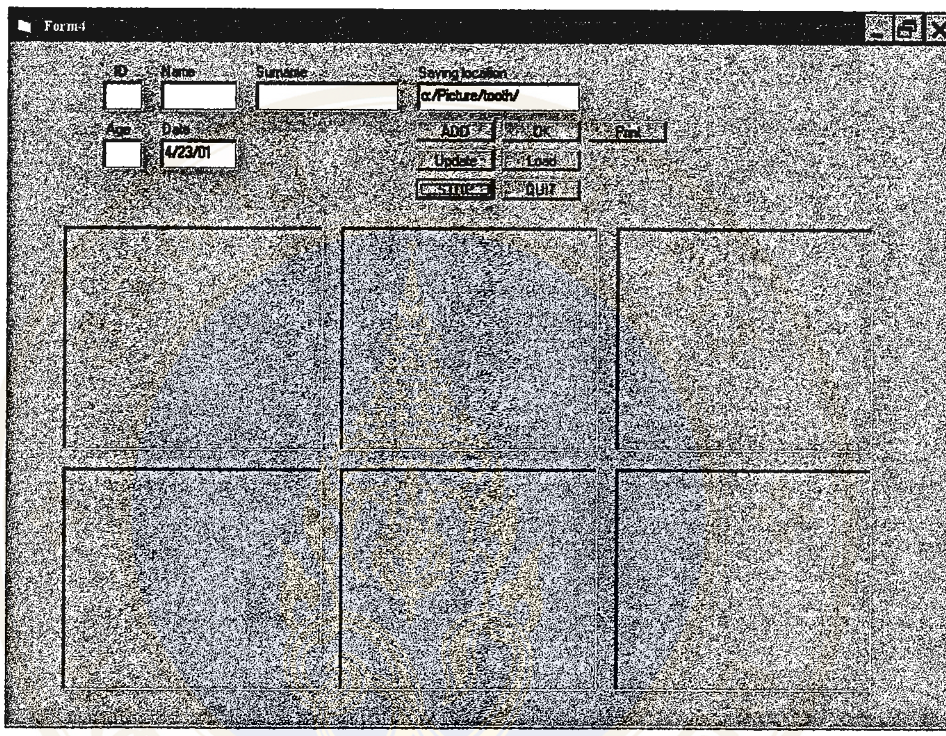

Figure 23 Database Window

The database window summarizes all of patient information from previous windows. The patient image can be recorded up to six images and these images can be selected freely depend on the orthodontist. These images are recorded in JPEG format to safe the memory which is used in storage patient information. This feature is very effective for the follow up to patient's tooth arrangement.

II. The tooth measurement

After the implementation process, the program is tested for accuracy. The method is done by performing 15 measurements of the same length. Then, analyze the result to obtain the program precision and accuracy. The test result is obtained as follow.

1. The anterior tooth size

By using the images obtained from the front and top view, the result of the calculation is shown in the table below.

The method is to measure the length of a known distance for 15 times. Then, analyze these results to obtain the accuracy of measurement. The result of the measurement using the top and front view is shown in table 4 and 5 with respect to different coordinates.

Table 4 The result of measurement by using top and front view

	1			2			3			4		
	X	Y	Z	X	Y	Z	X	Y	Z	X	Y	Z
Expected Value	0	0	0	0	75	0	10	0	0	10	75	0
1	0.00	1.07	-0.57	0.00	75.82	0.61	9.81	1.25	-0.46	9.59	76.00	0.12
2	0.00	0.88	-0.40	0.00	75.86	0.32	9.87	1.05	-0.13	9.64	76.00	-0.02
3	0.00	1.02	-0.27	0.00	75.82	0.60	9.87	1.04	-0.29	9.61	76.00	-0.19
4	0.00	1.02	-0.27	0.00	75.81	0.44	9.87	0.67	-0.14	9.60	76.00	-0.19
5	0.00	0.82	-0.28	0.00	75.81	0.44	9.86	1.10	-0.15	9.60	76.00	-0.19
6	0.00	1.02	-0.27	0.00	75.80	0.26	9.89	1.18	-0.14	9.64	76.00	-0.02
7	0.00	1.03	-0.10	0.00	75.62	0.58	9.93	0.89	0.02	9.58	76.00	-0.16
8	0.00	1.01	-0.43	0.00	75.75	0.55	9.89	1.19	0.02	9.63	76.00	-0.01
9	0.00	0.77	-0.16	0.00	75.75	0.54	9.93	1.07	0.03	9.63	76.00	0.15
10	0.00	1.14	-0.50	0.00	76.00	0.45	9.90	1.16	-0.13	9.58	76.00	-0.51
11	0.00	0.88	-0.42	0.00	75.55	0.53	9.90	0.93	-0.12	9.60	76.00	-0.18
12	0.00	1.02	-0.26	0.00	75.68	0.50	9.90	0.95	-0.13	9.64	76.00	-0.18
13	0.00	1.21	-0.41	0.00	76.06	0.33	9.89	1.38	-0.15	9.60	76.00	-0.03
14	0.00	0.98	0.02	0.00	75.67	0.28	9.90	0.97	-0.14	9.61	76.00	-0.51
15	0.00	0.83	-0.29	0.00	75.75	0.54	9.90	0.95	-0.13	9.64	76.00	-0.02
SUM	0.00	14.70	-4.61	0.00	1136.75	6.97	148.31	15.78	-2.04	144.19	1140.00	-1.94
AVERAGE	0.00	0.98	-0.31	0.00	75.78	0.46	9.89	1.05	-0.14	9.61	76.00	-0.13
ERROR	0.00	0.98	-0.31	0.00	0.78	0.46	-0.11	1.05	-0.14	-0.39	1.00	-0.13

TTEST for X1:X2 = 0 X3:X4 = 1.1623E-14

Y1:Y3 = 0.0614 Y2:Y4 = 8.4665E-06

Z1:Z3 = 0.0003 Z2:Z4 = 5.5286E-09

Table 5 The result of measurement by using top and front view

	1			2			3			4		
	X	Y	Z	X	Y	Z	X	Y	Z	X	Y	Z
Expected Value	50	0	0	50	75	0	40	0	0	40	75	0
1	49.5	0.75	0.08	49.3	75.91	0.13	40.01	0.81	-0.32	40.35	75	-0.41
2	49.49	0.77	-0.07	49.32	75.74	0.28	39.8	0.63	-0.59	40.15	75	-0.66
3	49.48	0.65	-0.09	48.89	76.14	0.06	39.8	0.76	-0.43	39.91	76	-0.95
4	49.51	0.59	0.08	49.69	75.9	0.62	40.02	0.45	-0.02	40.13	75	-0.52
5	49.5	0.6	-0.07	48.9	76.13	0.21	40.26	0.27	-0.03	40.11	76	-0.55
6	49.48	0.65	-0.09	49.3	75.93	0.41	40	0.68	-0.19	40.37	75	-0.07
7	49.89	0.59	0.42	49.7	75.74	0.62	40.02	0.63	-0.32	40.13	76	-0.53
8	49.08	0.69	-0.44	49.28	76.11	0.26	40.04	0.4	-0.14	40.12	75	-0.54
9	50.32	0.19	0.64	49.32	75.87	0.14	40.24	0.63	-0.04	40.13	76	-0.53
10	49.5	0.6	-0.07	46.69	75.9	0.62	39.81	0.58	-0.42	40.12	75	-0.54
11	49.51	0.59	0.08	49.3	75.93	0.41	40	0.81	-0.18	40.12	75	-0.39
12	49.48	0.8	0.06	49.3	75.93	0.41	39.8	0.63	-0.59	39.88	76	-0.83
13	49.9	0.56	0.28	50.12	75.5	0.84	40.02	0.63	-0.32	40.34	75	-0.41
14	49.46	0.97	-0.09	50.12	75.51	1.12	40.03	0.58	-0.15	40.1	75	-0.1
15	49.88	0.45	0.12	49.33	76.01	0.44	40.04	0.4	-0.29	40.36	75	-0.09
SUM	743.98	9.45	0.84	738.56	1138.25	6.57	599.89	8.89	-4.03	602.32	1130.00	-7.12
AVERAGE	49.60	0.63	0.06	49.24	75.88	0.44	39.99	0.59	-0.27	40.15	75.33	-0.47
ERROR	-0.40	0.63	0.06	-0.76	0.88	0.44	-0.01	0.59	-0.27	0.15	0.33	-0.47

TTEST for X1:X2 = 0.0489 X3:X4 = 0.0010

Y1:Y3 = 1.0955E-33 Y2:Y4 = 0.0002

Z1:Z3 = 0.0004 Z2:Z4 = 2.1250E-09

2. The posterior tooth size

This method is similar to the first one, except the top and side view is used instead of the top and front view.

Table 6 The result of measurement by using top and side view

	1			2			3			4		
	X	Y	Z	X	Y	Z	X	Y	Z	X	Y	Z
ExpectedValue	0.00	0.00	0.00	30.00	75.00	0.00	30.00	0.00	0.00	0.00	75.00	0.00
1	0.00	3.15	-1.17	30.08	108.43	-0.85	30.42	39.97	-1.95	0.00	79.00	-0.78
2	0.00	5.09	-1.11	30.17	14.53	-0.98	30.24	25.40	-1.14	0.00	81.00	-0.49
3	0.00	5.86	-1.10	30.20	112.90	-0.71	30.36	33.72	-1.09	0.00	80.00	-1.05
4	0.00	7.15	-1.34	29.97	97.76	-0.35	30.27	27.61	-0.96	0.00	80.00	-1.05
5	0.00	4.44	-1.11	29.88	91.66	-0.22	30.30	32.40	-1.77	0.00	79.00	-0.48
6	0.00	3.68	-0.88	29.88	90.92	-0.45	30.36	32.97	-1.32	0.00	78.00	-0.83
7	0.00	3.68	-0.88	29.85	89.45	-0.40	30.39	38.50	-1.90	0.00	79.00	-0.52
8	0.00	3.44	-0.60	30.09	104.59	-0.76	30.30	33.14	-1.54	0.00	79.00	-0.76
9	0.00	5.09	-1.11	29.97	97.02	-0.58	30.36	32.97	-1.32	0.00	81.00	-0.76
10	0.00	4.44	-1.11	29.78	84.81	-0.31	30.27	31.67	-1.49	0.00	80.00	-1.04
11	0.00	5.09	-1.11	30.06	105.48	-1.26	30.45	37.60	-1.91	0.00	81.00	-0.76
12	0.00	5.33	-1.39	30.15	12.32	-1.16	30.27	32.41	-1.27	0.00	78.00	-0.81
13	0.00	4.68	-1.39	29.72	77.82	0.32	30.42	41.45	-1.50	0.00	79.00	-0.76
14	0.00	2.91	-0.89	30.17	113.79	-1.21	30.30	32.40	-1.77	0.00	79.00	-0.77
15	0.00	3.15	-1.17	29.78	84.81	-0.31	30.24	25.40	-1.14	0.00	82.00	-0.98
SUM	0.00	67.18	-16.36	449.75	1286.29	-9.23	454.95	497.61	-22.07	0.00	1195.00	-11.84
AVERAGE	0.00	4.48	-1.09	29.98	85.75	-0.62	30.33	33.17	-1.47	0.00	79.67	-0.79
ERROR	0.00	4.48	-1.09	-0.02	10.75	-0.62	0.33	33.17	-1.47	0.00	4.67	-0.79

TTEST for X1:X4 = 0.0000 X2:X3= 2E-06

Y1:Y3 = 1.9239E-12 Y2:Y4 = 0.2313

Z1:Z3 = 0.0025 Z2:Z4 = 0.0956

Table 7 The result of measurement by using top and side view

	1			2			3			4		
	X	Y	Z	X	Y	Z	X	Y	Z	X	Y	Z
Expected Value	0.00	0.00	0.00	0.00	75.00	0.00	30.00	0.00	0.00	30.00	75.00	0.00
1	0.00	0.21	-0.42	0.00	75.80	-0.08	30.18	30.18	-1.69	29.91	89.00	-0.40
2	0.00	0.21	-0.73	0.00	75.15	-0.09	30.18	16.93	-0.96	29.87	84.00	0.41
3	0.00	0.62	-0.14	0.00	75.92	-0.07	30.27	23.03	-1.10	29.78	77.00	0.31
4	0.00	4.68	-1.39	0.00	81.44	-1.00	30.42	40.71	-1.72	30.15	113.00	-0.94
5	0.00	3.92	-1.16	0.00	78.20	-1.07	30.21	27.77	-1.18	29.94	99.00	-0.62
6	0.00	3.68	-0.88	0.00	79.08	-1.05	30.30	33.88	-1.31	29.99	98.00	-0.63
7	0.00	5.74	-1.11	0.00	80.79	-1.00	30.30	33.88	-1.31	29.94	98.00	-1.08
8	0.00	2.79	-0.60	0.00	78.86	-0.82	30.30	33.88	-1.31	29.64	79.00	-0.40
9	0.00	3.56	-0.59	0.00	78.97	-0.81	30.36	40.87	-1.95	29.88	91.00	-0.45
10	0.00	3.92	-1.16	0.00	78.08	-0.78	30.51	47.55	-1.63	30.09	105.00	-0.76
11	0.00	5.86	-1.10	0.00	79.84	-1.28	30.30	32.40	-1.77	29.94	98.00	-1.08
12	0.00	3.68	-0.88	0.00	78.44	-1.11	30.30	33.14	-1.54	30.06	106.00	-1.03
13	0.00	3.68	-0.88	0.00	78.08	-0.78	30.36	32.23	-1.55	29.99	99.00	-0.40
14	0.00	3.15	-1.17	0.00	79.72	-1.29	30.30	33.14	-1.54	29.99	98.00	-0.85
15	0.00	1.97	-0.92	0.00	78.08	-0.53	30.39	39.98	-1.45	30.11	106.00	-0.81
SUM	0.00	47.67	-13.13	0.00	1176.45	-11.76	454.68	499.57	-3.39	449.28	1440.00	-8.73
AVERAGE	0.00	2.98	-0.82	0.00	73.53	-0.74	28.42	31.22	-0.21	28.08	90.00	-0.55
ERROR	0.00	2.98	-0.82	0.00	-1.47	-0.74	-1.58	31.22	-0.21	-1.92	15.00	-0.55

TTEST for X1:X2 = 0.0000 X3:X4 = 3.1340E-09

Y1Y3 = 3.5490E-11 Y2:Y4 = 1.9510E-06

Z1:Z3 = 1.4170E-05 Z2:Z4 = 0.0060

The test result shows that the front and top view have a higher accuracy compared to the side and top view. The errors in the side and top view is very significant compared to the errors in the top and front view.

CHAPTER V

DISCUSSION

This section discusses the implementation of the system, which is designed for displaying and analyzing dental cast images on a PC-based system. In the analyzing part, analysis functions, including Bolton analysis and Kitti Sinepan formula, can be performed easily. The examples of the program results are shown in chapter IV, and the discussion of the result is as follow.

- From the test in Chapter IV, the program shows that the quality of measurement is highly depended on the quality of lens. That is, a low quality lens is mostly made of plastic, which produces high distortion as well as bad focusing.
- The camera position also affects the result of measurement. In this project, side cameras need to be placed in an inclined position in order to produce a best image view. Unfortunately, this technique also produces image distortions.
- Material used in the system, including the electrical system and mechanical system, has to be chosen carefully in order to produce lowest lost of data transfer, and also reduce noise.
- The software is developed using Microsoft Visual Basic 6.0 as an application tool for program coding, which is a high-level language. Therefore, the speed of operation is slow, especially in the image acquiring process.

Therefore, the error occurs in all measurement systems can be divided into four types as follow.

1. Human Error

This error occurs in every kind of measurement systems that are operated by human because each operator processes different measurement techniques and skills. This variation also occurs in different measurements from the same operator.

In this research, human error is also occurred because the system required orthodontists to manually locate the points to measure the distance. Anyway, this kind of error is susceptible in this research.

Unfortunately, the accuracy of this error cannot be calculated since the system cannot distinguish the error from human error and internal error. However, the results of measuring the same position and length for several times produce a very high precision. Therefore, human error is insignificant in this measurement.

2. Mechanical Error

This kind of error occurs from two factors, which are object movement and surface contact. In this orthodontic device, the design has been carefully made to prevent mechanical error because this error highly affects the measurement result. Anyway, it becomes almost hardly reduce this kind of error in a moving system. Therefore, the system in this research is design to prevent any kinds of movements in the system, including the object and the measuring device. Thus, this orthodontic device is designed to have a higher number of cameras to replace the movement technique. The minimum amount of camera required to capture the complete orthodontic image is four.

This technique captures the image and measures the distance from the image before translates the result to the real length value, which can highly reduced the error due to surface contact. This is very important especially in the measurement system, which requires a high accuracy. Moreover, measuring a non-rigid or complicate object also increase mechanical error in the system.

3. Hardware Error

In this research, the hardware error came largely from the cameras. This is due to the lens quality and the internal error of the camera. Moreover, the image result shows that high distortion occurs at the edge of the image, and the focal point of the lens is also not located at the center of the image, which are due to the lens quality.

Another factor is the Charged Couple Device (CCD) location, which can be misalign with the measurement plane. This highly affects the measurements because the technique assumes that the CCD plane is aligned with the image plane. These errors are highly due to poor assembly technique, or poor lens quality.

The solution to reduce this error is to use higher camera quality, which has high assembly technique and lens quality. However, the price is also very expensive. Another solution is to use a higher calibration technique, which can provide higher error reductions. It is suggested that a further research should be done in order to obtain the best solution.

4. Software Error

Software error can occur from poor programming technique, which often occurs in high calculation techniques. Anyway, this kind of error can be prevented by program testing and debugging. Moreover, software error always produces the same error, which can be recognized easily. Therefore, there is no software error found in this research because the program has already been carefully tested and debugged.

CHAPTER VI

CONCLUSION

The main objective of this thesis is to develop a system, which can measure and analyze the dental cast model in orthodontics. The system was developed to work with a personal computer on a Windows system. Moreover, the program was designed to have a user-friendly interface to facilitate user with greater ease and flexibility.

The program was divided into two main parts, the hardware and software part. The hardware part consists of both electrical and mechanical system to control the camera. The software part acquires the dental cast image and analyzes the data obtained. Both two parts were combined, and results in an easy-to-use interface.

The advantages of this program are as follow:

- To facilitate orthodontists in orthodontics planning.
- To reduce the time used in conventional analysis, which is a manual calculation.
- To reduce the cost of documentation through the use of digital format.
- To reduce the high cost of purchasing commercially available software
- To provide a base for further development in orthodontics

Though this program has been analyzed and designed carefully, there are still some restrictions as follow:

- The program can only display 2D dental cast images. The 3D image construction is not allowed.

- The program cannot measure the molar tooth size, since the accuracy is too low due to the lens quality and camera position.
- The program cannot measure tooth size with complex structures.
- The program speed of capturing image is still low because there is a speed limitation in changing the connection from one camera to the other.

The result of system development for this thesis can be used as a base for further system development, which is highly recommended. The main problem being discovered in this thesis is the measurement errors due to hardware quality and camera position. Therefore, in order to implement the system for commercial usage, more advanced techniques is required, including calibration techniques and higher lens quality.

RECOMMENDATIONS

- The software covers mainly the basic functions required for dental analysis. Therefore, further developments could be performed to provide higher software capability, especially the database management.
- According to the test result, the system errors are highly due to the material used in the system, especially the lens quality. Therefore, further developments can be made to reduce the system errors by improving the quality of material used.
- Other development tools such as C and Visual C++ could be used to produce higher speed of operation.

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