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Measuring Propeller Pitch Based on Photogrammetry and Computer-aided Design

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There are a number of methods for measuring propeller pitch, but there could still be problems for many fishing boat builders because of their lack of necessary professional equipment. This paper presents a method of propeller pitch measuring based on photogrammetry and CAD (Computer-Aided Design). This method consists of three stages. The first stage is to take a series of 2D image photographs of the propeller using a smart phone. The second stage consists of processing these 2D images using photogrammetry software to create a 3D virtual model of the propeller. A CAD program is used to measure the pitch at different radii of each blade of the 3D virtual model in the third stage. In this study, several propellers for fishing boats were measured and the results were compared to those archived by using an EDM (Electrical Discharge Machining) machine and by a qualified professional worker using simple tools. The measurement results showed that the proposed method would be acceptable for measuring pitches of propellers of fishing boats.

Keywords: Computer-Aided Design, Fishing boat, Measurement, Photogrammetry, Pitch, Propeller

1 Introduction

A propeller is one of the most important components of a fishing boat. It converts rotational motion into thrust which enables either forward or reverse movement of a boat in water. There are two variants of screw propellers being constant pitch and controllable pitch. In the constant pitch, the blade is fixed onto the hub, whereas in the controllable pitch the blade can be rotated on the hub. Fishing boats mainly use the constant pitch propeller. A propeller should be inspected during the manufacturing process to ensure compliance with the design. At a boat building site, some important parameters of the propeller need to be measured to ensure that the propeller would satisfy the requirements of the propulsion system. The propeller should also be inspected during its service life to examine its condition in service. There are many parameters of a propeller which should be inspected. Some of them are geometric parameters such as diameter, pitch and section chord length.

Traditionally, contact measuring methods have been used for the inspection of propellers. Gauges, pitch meters and coordinate measuring machines, which are manually or CNC (Computer Numerical Control) operated, can be used to measure the pitch [1, 2, 3, 4]. Gauges and pitch meters are inexpensive but less accurate than coordinate measuring machines. Coordinate measuring machines are more accurate but they are expensive. [5, 6] Furthermore, the size of the propeller which needs to be measured is restricted by the sizes of the measuring tools and equipment.

Currently, non-contact methods can be applied for the inspection of propellers. In non-contact methods, the physical model of a propeller can be digitized into a 3D virtual model [7]. From the virtual model, the pitch of the propeller can be determined. Previous studies show that the digitization process of propellers utilized costly equipment such as 3D scanners [8, 9, 10, 11], machine vision system [12], and even low cost equipment such as digital cameras [13, 14]. Using 3D scanning systems and machine vision systems would offer a highly accurate inspection of propeller blades. However, in general, these systems are still very expensive. In contrast, photogrammetry techniques are less accurate but much cheaper and they could be considered as low cost methods for 3D measurement in shipbuilding [15].

Although a number of methods for measuring propeller pitch are available it is still an issue in Vietnam where currently over 110.000 fishing boats are in service. In Vietnam, pitch inspection is a requirement in any new building, repairing or registration of fishing boats. For each fishing boat, the builder should inspect the propeller pitch. The pitch is then checked again by the local authority. Because of the lack of measuring instruments, most fishing boat builders perform pitch inspections manually with basic tools such as a protractor, a square set and a compass. This task is time consuming and less accurate than digital methods and the measured results can be unacceptable in many cases. This means that new methods need to be sought which can satisfy the requirements of Vietnamese fishing boat builders who are small in size but large in quantity. A new method to measure propeller pitch for fishing boats is presented in this paper. Based on photogrammetry techniques, 2D images of a propeller were used to create a 3D virtual model. Then, in CAD environment, the propeller pitch was measured on the virtual model according to the principle described in ISO 484-2 standard [3]. A smart phone was used to take the photos of the propeller, and Agisoft Metashape (Agisoft LLC, Russia) and CATIA (Dassault Systèmes, France) were the software used for modelling and measuring purposes.

2 Methodologies

2.1 Image acquisition

Reconstructing the 3D model of a physical object based on its 2D images is a technique which has been widely used in photogrammetry. At the moment, some sotfware packages are available for image-based 3D reconstruction. This study used Agisoft Metashape for photogrammetric processing of 2D images in order to create 3D virtual models of propellers.

The input data for Agisoft Metashape is photos taken by any digital camera as long as they satisfy specific capturing guidelines. It is recommended that a digital camera with a resolution of 5 megapixels or higher and a focal length from 20 to 80 mm interval in 35 mm equivalent can be used for capturing [16]. In this study, an iPhone 6S which has a 12-megapixel camera with a focal length of 29 mm was used. Some camera settings were as follows:

- The photos were saved in JPEG format.
- The International Organization for Standardization (ISO) value was 25. This is the lowest value to prevent additional noise to images.
- Aperture was 2.2 mm. It is high enough to capture sharp, not blurred photos.
- The lenses of the camera were fixed during taking photos.
- No flash was applied.
- Shutter speed was 1/50 second, this value is good enough to ensure that blur cannot occur due to slight movements.

Agisoft Metashape allows the use of coded targets to improve accuracy. However, in order to achieve higher accuracy, this study used a 25 mm cylinder as a gauge for scaling the virtual model to its real dimensions. This cylinder was placed coaxially on the hub (Fig. 1). When capturing the photos, the propeller was not moving. The photos were taken by the smart phone which was moved around the propeller in such a way as to allow an overlap of about 60-80% between two consecutive images. The distances between the smart phone and the propeller were from 0.5 m to 1.0 m. It is not necessary to take photos on both sides of the propeller because the pitch measurement is only applied on the pressure side of the propeller.

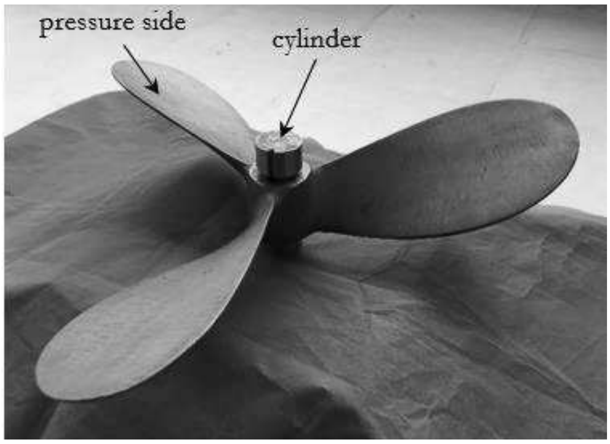


Fig. 1 *Capturing photos of propeller*

2.2 Image processing

In Agisoft Metashape, several steps are required to process images and create 3D models. The followings are some main steps used in this study.

- *Loading, aligning photos and generating sparse point cloud.* In this step, the photos of a propeller are first loaded into Agisoft Metashape. After that, the software searches for finding feature points on the loaded photos and then matches them into tie points. This procedure results in a generation of a sparse point cloud and a set of camera positions.
- *Building dense point cloud.* The sparse point cloud is processed into a dense cloud based on the estimated camera positions and their loaded images. A high-quality dense cloud can be applied to obtain highly detailed and accurate geometry.
- *Building mesh and generating texture.* This step creates the polygonal model of the propeller by generating a set of three adjacent points which represents the surfaces of the propeller. Higher quality settings were also performed. Then, the polygonal model was textured in order to get a photorealistic model of the propeller.
- *Exporting 3D model.* In this step, an STL model

can be exported for further processing in CAD environment.

In this study, the STL model, which is the result of the image processing stage in Agisoft Metashape version 1.7.0, was used for pitch measurement in CATIA V5R2019. The principle of pitch measurement and measuring procedure in CATIA is presented in the next subsection.

2.3 Pitch measurement

The pitch of a propeller indicates the axial distance that the propeller will move forward for one revolution of the propeller shaft. ISO 484–2 standard recommends 3 methods to measure the pitch by using marking gauge, graduated ring and coordinate measuring machine. These methods adopt the principle measurement illustrated in Fig. 2 [3].

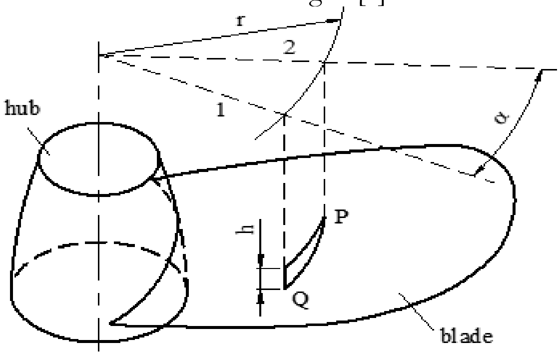


***Fig. 2** Principle of pitch measurement*

The principle measurement consists in setting out along a helicoidal line of radius r a certain length PQ, corresponding to the desired angle α, and in measuring the difference h in height between two points P and Q with respect to a reference plane. The points P and Q are on the pressure side of the blade. Depend on the accuracy of the propeller, the pitch shall be measured at different radii as recommended in ISO 484-2. The pitch per radius and per blade is defined by multiplying h by $\frac{360}{\alpha}$. The arithmetic mean of the pitches per radius of the blade is the mean pitch per blade.

The above principle was used in this study. However, the measuring procedure was performed on the virtual model in CATIA. After the STL model was generated, it was imported in Digitized Shape Editor module of CATIA. Because the generated STL model was an unscaled model, it needs to be scaled in order to obtain an accurate one. Firstly, the cylindrical surface of the cylinder was regenerated by using Basic Surface Recognition tool. Secondly, a scale was performed to obtain the scaled model. The scale ratio is the ratio of the diameter of the cylinder (measured by using a new digital micrometer) and the diameter of the new cylindrical surface (measured in CATIA).

Once having the scaled model of the propeller, the pitch at a certain radius of a blade was measured by the following main steps:

- Firstly, in CATIA, two reference points on the pressure surface of the blade at the radius to be measured were determined (points P and Q in Fig. 3). These points can be separated by any angle but they must be within the limit of the blade surface. Here, an angle of 20o was chosen. This step was mainly done in the Sketch environment with some main sketch tools such as Circle, Line and Point. Zooming in is also helpful to create the reference points more precisely.

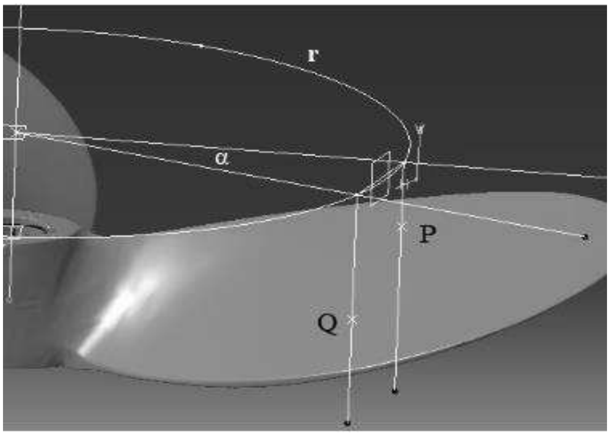


***Fig. 3** Creating reference points*

- Secondly, the difference in height of the two reference points P and Q was determined by using command *Measure Between* in the Sketch environment of CATIA (Fig. 4). The command *Line* and some constraints such as *Parallelism* and *Perpendicular* can be also used to facilitate the measuring task.

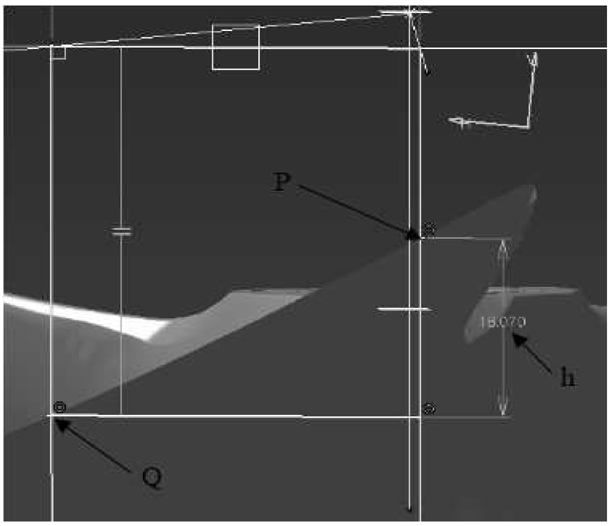


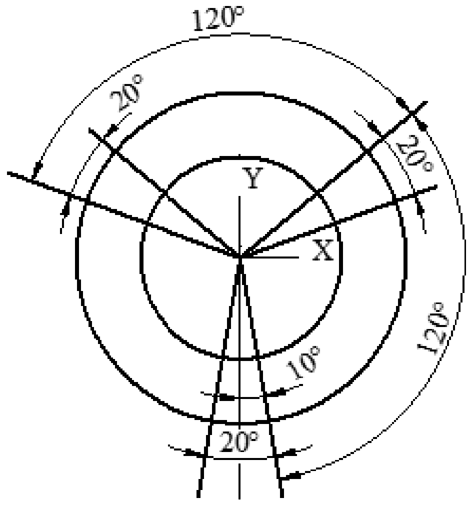
***Fig. 4** Measuring the difference in height between reference points*

- Finally, the pitch was calculated by multiplying the h value (obtained form the second step, illustrated in Fig. 4) by 18 (that is $\frac{360}{20} = 18$).

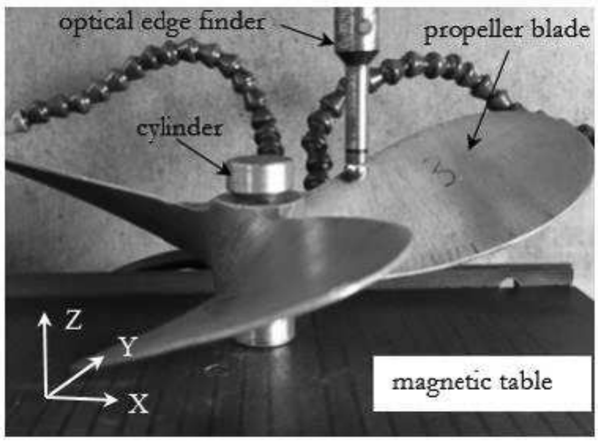
The pitch measurements were performed at 8 radii: r = 0.3R, r = 0.4R, r = 0.5R, r = 0.6R, r = 0.7R, r = 0.8R, r = 0.9R, r = 0.95R, where R is the radius of the propeller.

In this study, the proposed method was applied on 3D virtual models reconstructed from data which obtained by a 3D scanner (ATOS Core 300, GOM, Germany) and by a smart phone (iPhone 6S). The measurement results from the 3D virtual models were also compared to those obtained on the physical model, with the same measurement principle, by using a CNC machine and by a professionally skilled worker using simple tools.

Because of lacking coordinate measuring machines, a die-sinker EDM machine (TopEDM, Tai-I Electron Machining Co., Taiwan) was used. An optical edge finder was clamped on the head of the machine and it was used for setting up the measuring operations and getting the coordinates of the measured points. In order to obtain the difference h between two measurement points (P and Q), the following steps were fulfilled. Firstly, X and Y coordinates of the measurement points at every radius of each blade were predefined. In Mechanical workspace of AutoCAD Mechanical (Autodesk, USA), 8 concentric circles with the center at the origin on the XY plane, their radii corresponding to the radii to be measured, were drawn and then 6 straight lines through the center of the circles were created as shown in Fig. 5a (there are only 2 circles in this figure for easy viewing). The straight lines represent lines 1 and 2 in Fig. 2 for each blade. The X and Y coordinates of the intersection points between these circles and straight lines are the coordinates of the points to be measured. *Multiple Points* command can be used to get the coordinates of the intersection points. Next, on the EDM machine, the propeller was carefully adjusted on the magnetic table providing that one of its blades was pointing in -Y direction as in Fig. 5b, and clamped securely. The centering function of the EDM machine was used to determine the center line the cylinder, and the reference point for measurement (on the top and at the center line of the cylinder) was set up. Then, for each blade, at each radius, the Z coordinates of 2 measured points were determined by moving the edge finder to the predefined X and Y coordinates of each point, then lowering it automatically until it touched the blade surface. Lastly, the Z coordinate displayed on the display screen of the machine was read and noted down. The difference between the two measurements is the h value.



a)



b)

***Fig. 5** Measuring pitch on an EDM machine: (a) concentric circles and straigh lines to predefine X and Y coordinates of the measurement points; (b) setting up the propeller on the machine table*

A specialist from a local ship builder was invited to measure the pitches. Firstly, the diameter of the propeller and the hole diameter of the hub were measured by using a steel ruler with a graduation of 0.5 mm. In Mechanical workspace of AutoCAD Mechanical, 7 concentric circles in with the radii corresponding to 7 radii to be measured were created (there was no measurement at the radius of 0.95R). A smallest concentric circle which stands for the hub hole was also drawn. A blueprint which has these circles was printed on the scale of 1:1. The propeller was carefully put on the blueprint which was lying on a table so that the hub hole coincided with the smallest circle. Based on 7 concentric circles, measurement points P and Q on the edges of the blades, and their projections on the blueprint, were marked by using a square bar and a pencil, as illustrated in Fig. 6. Finally, from the marks on the edges of the blade, the differences h between points P and Q were obtained by comparing the height of the two points by a steel ruler. The marks on the blueprint were used to determine angle α by a protractor for each measurement. From the values of h and α, the pitches at every radius per blade were calculated.

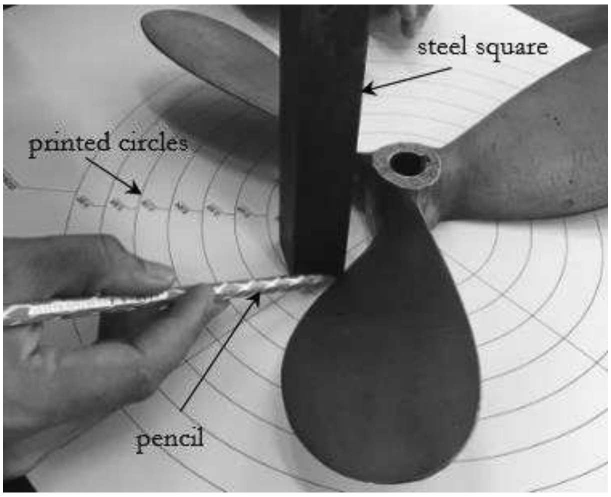
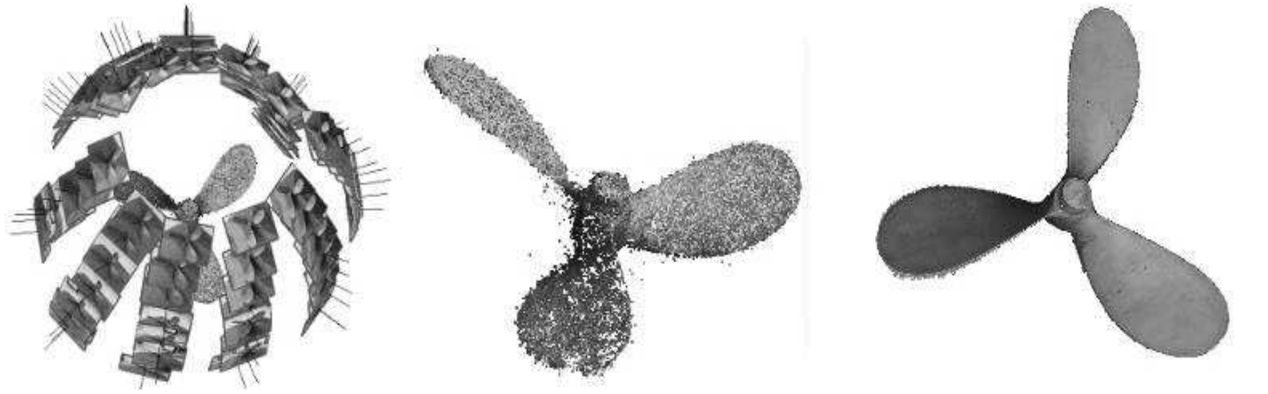


Fig. 6 *A step of measuring pitch with simple tools*

3 Application

In this study, a number of propellers for fishing boats were utilized as the measurement objects to show the effectiveness of the proposed method. A typical case is presented for the purpose of demonstration in this paper. This is a 3-blade cast bronze propeller for fishing boats, manufactured by a domestic manufacturer. It is about 339 mm in diameter but unknown pitch (buying an unknown pitch propeller is a common situation in fishing boat building in Vietnam).

93 photos of the propeller were taken out door on a sunny day. In Fig. 7, from left to right, are the sparse point cloud with the set of camera positions, the dense point cloud model and the textured model of the propeller in Agisoft Metashape. It took about 3 minutes, 14 minutes and 4 minutes respectively for the first 3 main steps of image processing on a desktop computer (CPU AMD Ryzen 7 2700X, 3.7GHz, 16GB of RAM), operating under Microsoft Windows 10. The measuring time in CATIA was about 1 hour. The STL model of the propeller obtained by the ATOS Core 300 is illustrated in Fig. 8 (imported into CATIA).



a) *b)* *c)*

Fig. 7 *Different stages of image processing: (a) sparse point cloud; (b) dense point cloud model; (c) textured model*

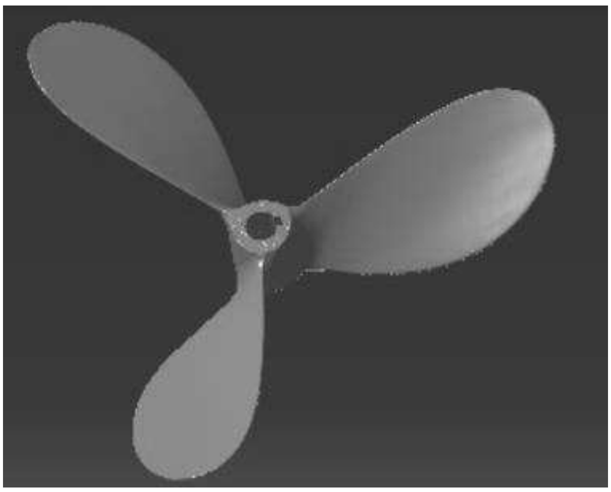


Fig. 8 *The STL model of the propeller obtained by 3D scanner*

The values of pitches at different radii and the mean pitches per blade obtained by different methodologies are presented in Tab. 1, Tab. 2 and Tab. 3. In these tables, P_{EDM}, P_{ATOS}, P_{2D}, P_{ST} are the pitches measured on a physical model by CNC EDM method, on a virtual model reconstructed by 3D scanning method, on a virtual model reconstructed by photogrammetry method, and on a physical model implemented by a qualified professional using simple tools, respectively. The measurement differences (Diff) of the mean pitches between those measured by CNC EDM method and the others are also reported.

From the measurement results, it can be seen that there are very small differences in the pitch values between the two virtual models. The maximum differences of the mean pitch are only 0.668 mm, 0.18 mm and 0.702 mm for blades 1, 2 and 3, respectively. This indicates that in this application, the accuracy of the virtual model created by photogrammetry is similar to that created by the ATOS scanner. It is obvious that the model reconstructed by 3D scanning has a very high accuracy and its integrity is ensured. Whereas, the photogrammetry based model in this study lacks features such as the hole on the hub and the surfaces on the suction side. It can take significant time for modelling a propeller with two sides. This is one of the limitations of the proposed method.

Tab. 1 *Local pitch on blade 1 [mm]*

r	P_{EDM}	P_{ATOS}	P_{2D}	P_{ST}
0.3R	287.046	288.540	290.304	287.3
0.4R	302.076	298.116	301.374	293.3
0.5R	314.280	317.790	316.080	308.8
0.6R	321.444	325.728	319.050	324.7
0.7R	328.824	325.314	329.616	324.2
0.8R	335.304	338.382	337.698	338.0
0.9R	347.256	341.280	348.336	350.1
0.95R	349.632	350.856	349.056	-
Mean	**323.233**	**323.251**	**323.939**	**318.1**
Diff	**-**	**+0.018**	**+0.707**	**-5.133**

Tab. 2 *Local pitch on blade 2 [mm]*

r	P_{EDM}	P_{ATOS}	P_{2D}	P_{ST}
0.3R	285.314	284.292	287.118	270.7
0.4R	299.106	298.728	299.124	278.2
0.5R	310.576	310.032	309.528	297.8
0.6R	314.344	314.370	315.450	299.6
0.7R	315.012	314.838	318.402	309.9
0.8R	317.233	322.200	323.604	312.0
0.9R	321.008	317.322	319.824	317.4
0.95R	308.441	308.916	299.088	-
Mean	308.879	**308.837**	**309.017**	**298.0**
Diff	**-**	**-0.042**	**+0.138**	**-10.879**

Tab. 3 *Local pitch on blade 3 [mm]*

r	P_{EDM}	P_{ATOS}	P_{2D}	P_{ST}
0.3R	293.634	289.116	294.930	283.2
0.4R	309.960	315.360	310.086	295.3
0.5R	314.406	322.254	319.284	311.5
0.6R	318.384	317.898	313.254	311.0
0.7R	311.346	317.574	316.566	323.8
0.8R	310.698	319.698	320.652	323.8
0.9R	335.880	324.126	326.970	317.5
0.95R	319.356	323.172	321.840	-
Mean	**314.208**	**316.150**	**315.448**	**309.4**
Diff	**-**	**+1.942**	**+1.240**	**-4.808**

In general, the mean pitch values measured on the virtual models are slightly larger than those measured on the physical model by the die-sinker EDM machine, but not significantly. By using the values of the mean pitch (per blade) obtained by the CNC EDM method as reference, it can be observed that the maximum differences between the mean pitch values measured by the virtual models to the reference values are 1.942 mm (on blade 3), equivalent to 0.6%. This error is acceptable in this case, despite the fact that errors still exist when measuring using the die-sinker EDM machine. In contrast, the mean pitch values measured on the physical model by a specialist are much smaller. The maximum difference between the pitch values measured on the physical model by the specialist to the reference values is up to 10.879 mm (on blade 2), equivalent to more than 3.5%. Depending on the type of fishing boats, propellers with medium accuracy or wide tolerances can be equipped. The accuracy class of the propeller can be selected by the customer [3]. For pitch measurement, an error of 3.5% can be acceptable for propellers with wide tolerances but it would not be acceptable in the case of medium accurate propellers. In terms of measurement results, it can be stated that the method which is based on photogrammetry and CAD (proposed method) would be accurate enough, and acceptable for many applications of measuring propeller pitch. In the proposed method, errors would mainly come from the stages of 2D data acquisition, image processing in Agisoft Metashape model scaling and determination of reference points in CATIA. It took more than 2.5 hours for the measurement of propeller pitches by the CNC EDM method while the local specialist needed approximately only one hour to complete the measurement task. It can be seen that the measurement time of the proposed method is longer than that of the local specialist. However, the proposed method could be accepted by local ship builders in terms of time.

In the studies of Ackermann et al. [13], Menna and Troisi [14], a close range photogrammetry technique was used for reconstructing the geometry of a small propeller, then the pitch was measured from the 3D model with a high degree of accuracy. However, their capturing method is complicated and time-consuming because they used a digital camera which needed to be calibrated with numerous circular coded targets on the propeller. In addition, reconstructing propeller blades in Geomagic Studio is a difficult task and specialist workers are needed. In our study, the proposed method used images taken by a smart phone without camera calibration and coded targets, hence it took only a short amount of time to capture. Moreover, the pitch measuring techniques in CATIA is relatively simple.

Other applications of this study also showed that the proposed method acquired fewer errors than those of measurements with simple tools and would satisfy the requirements of pitch testing by local fishing boat builders. It may be said that this method is low cost and would be a good choice for many applications if there is no pitch measuring equipment available and for propellers with wide tolerances or medium accuracy. In addition, the size of propellers would not be a problem when taking pitch measurements. However, it should be noted that the proposed method has some limitations such as it needs longer time compare to the manual method performed by the local specialist and CATIA should be available.

4 Conclusion

In this study, a new method of measuring pitch propellers is proposed. This is a combination of photogrammetry and CAD techniques. Agisoft Metashape, a photogrammetry software, was used to create the 3D virtual model of a propeller from its 2D images which were taken by a smart phone, using a cylinder as a gauge for further processing. In CATIA environment, the 3D virtual model of the propeller was scaled to adapt to the real size of the propeller and the local pitch at different radii of each blade were measured in a way that is recommended in ISO 484–2 standard. From the measurement results of the study, it can be stated that the proposed method could be used to measure the pitch of propellers for small fishing boats. Increasing the geometrical accuracy of the virtual models of the propellers in the image processing stage and applying the proposed method for propellers which are assembled on the boats are future work of this study.

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