



Use of RBF Morph mesh morphing for the estimation of airfoil performances in presence of ice profiles

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Abstract

This paper shows how mesh morphing can be effectively used as a tool for updating CFD models of wings into iced configurations, i.e. accounting for the presence of complex shapes originated during ice accretion. Although several approaches are well established for the prediction of ice build up, a robust method capable to continuously update the original geometry into the iced one is a paramount for automate calculation workflows suitable for ice accretion prediction and wing performances degeneration.

Thanks to the use of the mesh morphing software RBF Morph and the CFD solver ANSYS Fluent a method for automatic update of the mesh has been implemented. Presented results are based on Lewice 2.0 validation manual. Six benchmark shapes have been selected and the proposed workflow is capable to update the mesh from original to iced configuration (in this case final shapes are known in advance). At each intermediate step the quality of the morphed mesh is monitored. Wing performance is then examined considering both global

forces (polar plots) and local C_p profiles. Additional benchmarks were finally carried out to demonstrate the workflow in a tridimensional environment.

Introduction

Flying in icing atmospheric conditions can be a serious safety problem. Ice build-up generally occurs when supercooled droplets impinge on aircraft surfaces, most commonly the engine and the windward face of the wings, causing a variation in the overall vehicle fluid dynamics.

Ice accretions can increase the drag force and decrease the lifting characteristics of the aerofoil, so more power and a greater angle of attack is required to maintain flight conditions. Wing Icing causes not only stall to occur at lower attack angles, but an uneven ice distribution that can diminish dangerously the vehicle manoeuvrability.

In-flight icing has been responsible for more than 819 deaths and 583 plane crash in a 19 years span period between 1982 and 2000 in the USA only. Understanding and studying the icing problem is then of capital importance, and an ice accretion analysis has thus become a must during the design process. Ice build-up can be investigated by means of flight tests, wind tunnels or numerical simulations. Flight tests are the most realistic and the most expensive too, so they are used in certain conditions only or in the final stage of the analysis. Wind tunnels can recreate exact ice shapes, but the control over the dimensionless parameters can be very hard. Computational fluid dynamics by the other hand is widely used because it's a low cost alternative than can simulate relatively good the whole icing process, allowing to change instantly an infinite number of related parameters. Although historically NASA and DERA were the main contributors to the numerical models development, nowadays there are several different accretion models from all the major international agencies, such as Lewice (NASA), Trajice2 (DERA), Capta (ONERA), Multi-ice (CIRA) and fensap-ice (NTI).

A typical icing accretion model consists of two main modules that work seamlessly together. The first one deals with the droplets trajectory, and determines the collection efficiency distribution over the whole body. The second one computes a thermodynamic analysis to establish, given the collection efficiency, the ice thickness in any given point. Results from the accretion model can be then used to model a new shape in the analysis environment used for the fluid dynamic simulation. There has therefore to be a direct connection between the ice accretion model and the CFD solver, that can be used cyclically to compute back the flow field for the collection efficiency determination of the new configuration. Being able to generate a high quality grid in the shortest time possible is a major challenge as it is a possible bottleneck of the whole ice accretion analysis in terms of both time and quality.

Tools description

Radial Basis Functions (RBF) are powerful mathematical functions able to interpolate, giving the exact values in the original points, functions defined at discrete points only (source points). The interpolation quality and it's behaviour depends on the chosen radial basis function. In the field of mesh morphing radial basis functions find their natural application. Using RBF can be indeed modified the displacement at discrete points, and interpolated congruently every nodal position of the grid in a mesh independent fashion, as it deals with points positions only.

Radial Basis Functions are the ideal tool for the grid generation problem in an icing application. Instead of having to rebuild the mesh at every step to take into account new ice layers, the new shape can be obtained imposing the displacement required by the accretion model to the source points, and morphing accordingly the wing shape and the fluid domain using RBF. An important amount of time and computational resources can be saved integrating the RBF morpher into the work flow.

LEWICE 2.0 is an extensively tested ice accretion computer code developed by NASA that includes an analytical thermodynamic model for the freezing evaluation of the supercooled droplets. The final ice shape can

be modified varying the atmospheric and meteorological parameters such as velocity, pressure, temperature, liquid water content, relative humidity, droplet diameter.

2D and 3D Benchmarks

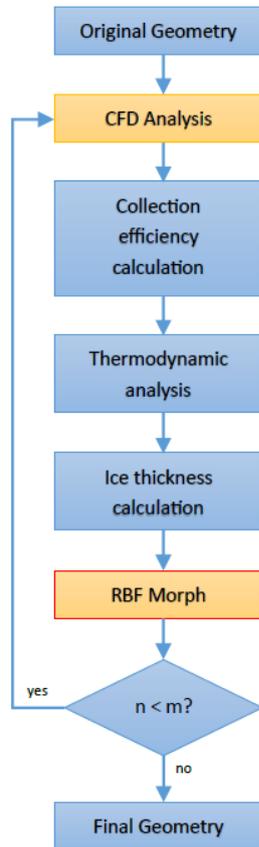


Figure 1 Proposed workflow

The ideal workflow proposed in this paper is displayed in Figure 1. The original Mesh geometry is used for the CFD analysis in the first step only: droplet trajectories and water volume content are then computed for the collection efficiency calculation. The results are used as inputs for the thermodynamic analysis that allows the ice thickness evaluation for every point of the surface. Finally translating ice thickness into nodal displacement allows to morph the interested domain using RBF Morph, generating the new iced geometry that can be used as a starting point for a new calculation cycle. The process can be executed cyclically for the number of step required.

To put the focus on the interested task and to showcase the ability of the RBF Morpher, the process has been simplified eliminating the need for an accretion model. 6 complete ice shapes were indeed taken from the lewice 2.0 validation manual and fed directly into RBF Morph, simulating the ice accretion model working output.

Original airfoil geometries

2 2-D clean wing geometries were used in this study. The NACA0012 profile has been widely used in icing tests over the years, and the GLC305 is representative of a business jet aerofoil. To be able to compare properly the results from the different accretion runs, was chosen to maintain the initial grid as similar as possible both in the NACA0012 and in the GLC305 related cases. A single mesh of a NACA0012 2D wing was then used as a starting point for all the simulations and, to assure the needed uniformity, radial basis functions were used when needed to change its shape into a GLC305 profile. While the NACA0012 profile was used for the first simulation, the GLC305 aerofoil was involved as a starting geometry in the remaining five.

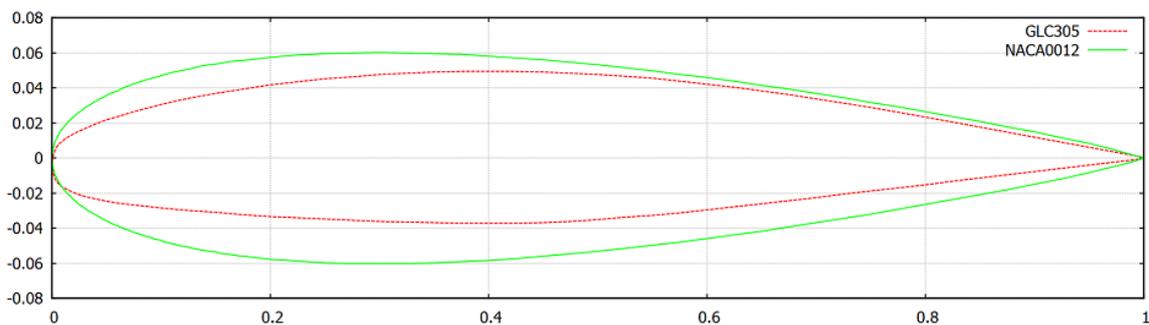


Figure 2 GLC305 and NACA0012 shapes

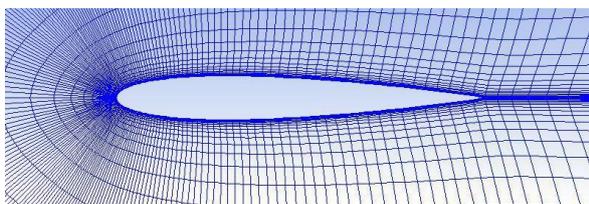


Figure 3 NACA0012 grid

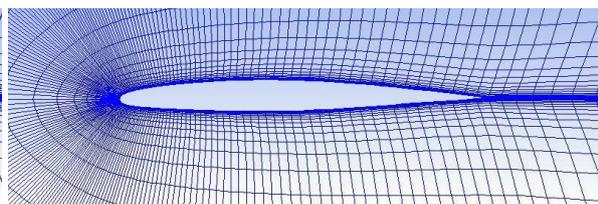


Figure 4 GLC305grid obtained through NACA0012 morphing

RBF Morph Setup

Even if in the case in study the icing shapes were already known in advance, source nodes displacements were given at steps, to simulate with a better accuracy the RBF morpher working inside the workflow and receiving only the information relative to the current calculation cycle. In the absence of the real accretion model ice build-up was simulated, without loss of generality, linear. Point displacements, in the RBF Morph environment, can be expressed as a relative distance in the independent axis directions or in the surface normal direction. Almost every ice accretion code already express the new ice layer thickness for every node along the surface normal, so the accretion code-RBF Morph coupling is particularly eased. To maintain finally the remaining portion of the domain geometry unaltered, a zero motion was imposed to the inlet and outlet boundaries source points using the included surfs option of RBF Morph.

Fluent Setup

To complete the workflow and to have a better insight into the behaviour of the iced geometries, every profile was examined and studied in ANSYS Fluent. The general domain used for all the carried CFD simulations, is shown in Figure 5. The two dimensional cell domain is composed by 9800 quadrilateral elements. With the exception of the wing profile, a Pressure far-field boundary condition was imposed to the inlet (c profile) and to the outlet (right border in Image 5). Simulations were carried using a pressure based double precision k-epsilon (two equations) turbulence model, modelling air after an ideal gas with a Sutherland viscosity behaviour. To couple pressure and velocity was used a SIMPLE scheme, and second order upwind spatial discretizations were used for density, momentum, turbulent kinetic energy, turbulent dissipation rate and the energy equations.

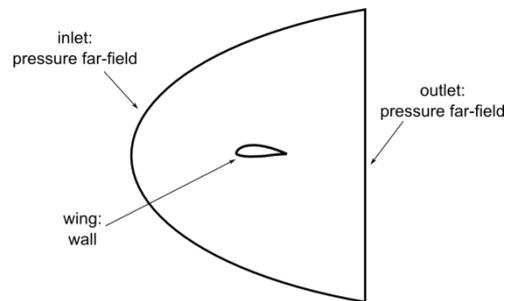


Figure5 cell domain used in the simulations

2D Benchmark

As demonstrated in Figure 6 the morphing action preserved grid quality during the accretion even for the most complex shapes. Grids for the completely accreted geometries are shown in Figure 7. CFD results were calculated for a 0.6 Mach flight and drag, lift and full polars were plotted for a 0-14 deg angle of attack range. Clean wings were investigated as well as intermediate and final stages of ice accretion. As expected ice accretions are generally responsible for an increasing of the drag force and a decreasing of the lift coefficient, as an effect of the early flow separation introduced by the deteriorated geometry. Pressure coefficients for the wing were calculated for clean and completely iced profiles for a 2 deg angle of attack. In Figure 8 the C_p curve and the full polar are displayed for run 1.

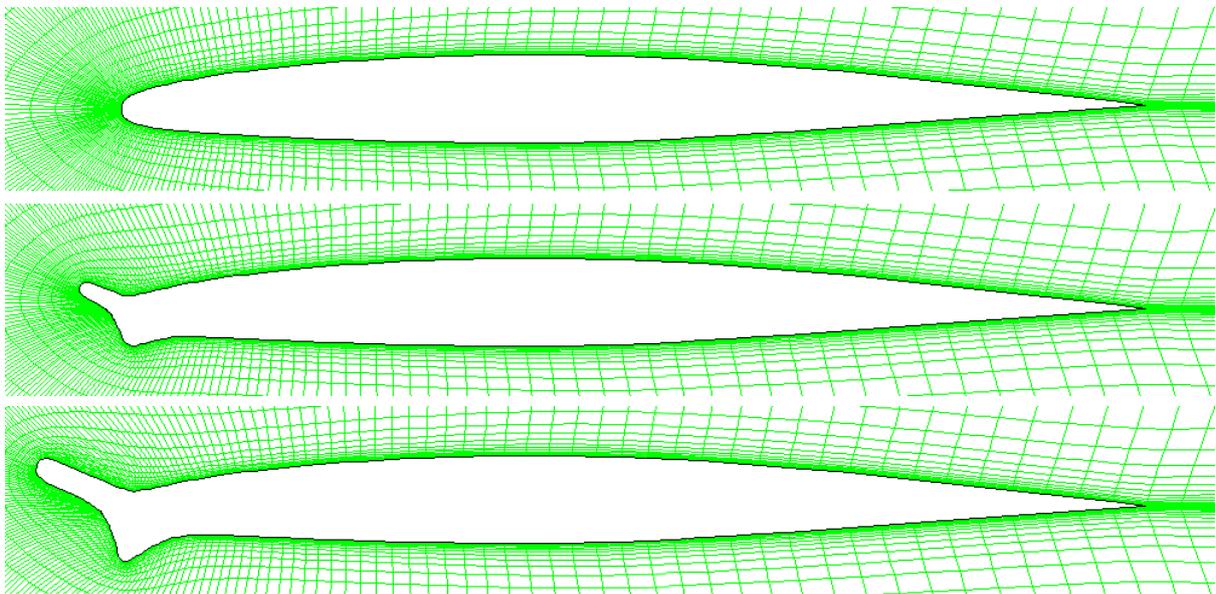


Figure6 clean, intermediate and complete accretion on a GLC305 geometry

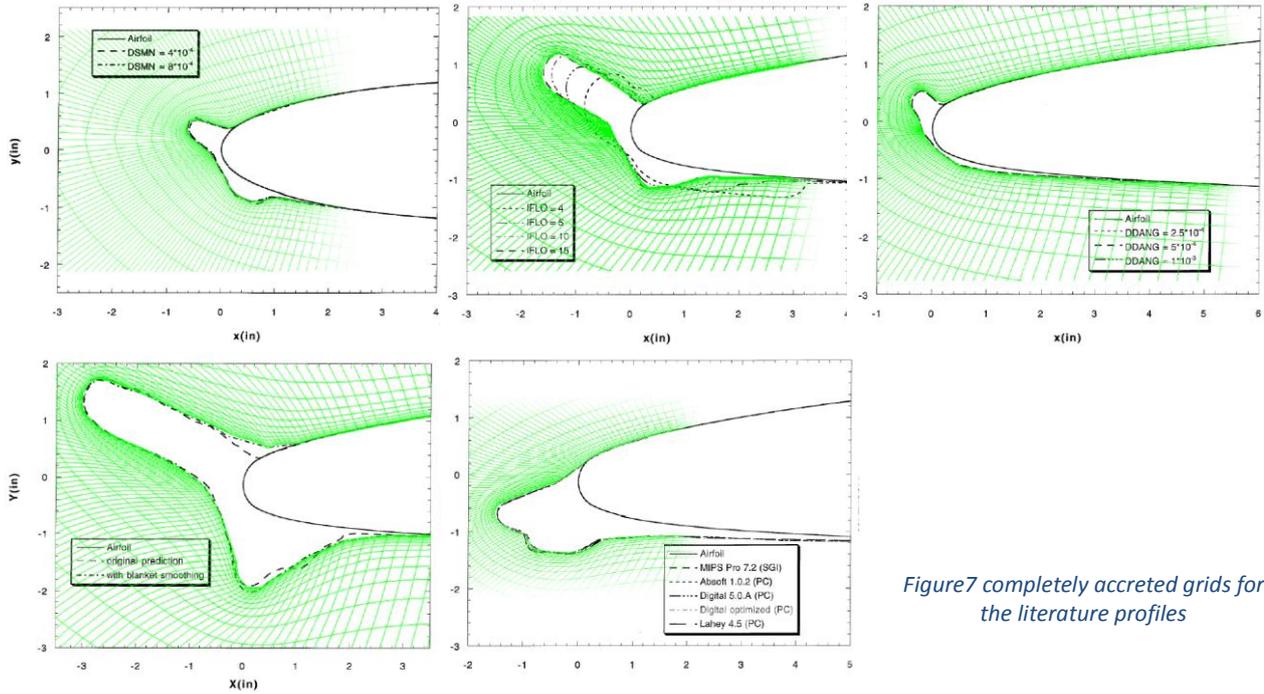


Figure7 completely accreted grids for the literature profiles

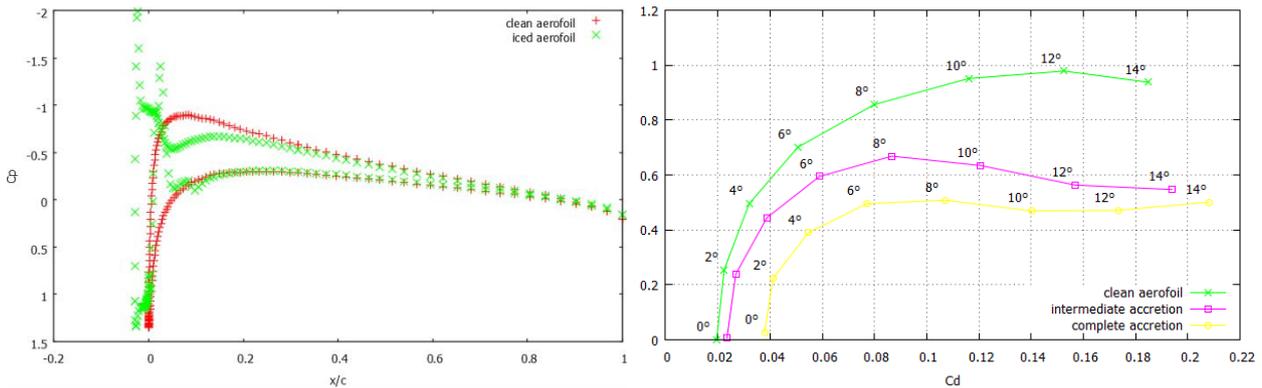


Figure8 Cp curve for clean and iced airfoil (baseline angle) and full polar for run 1

3D Benchmark

To demonstrate the feasibility of the already proposed icing analysis workflow for a 3D scenario, RBF Morph was tested at first in simple 3D evolutions of the 2D benchmarked cases. A clean 3D grid of the NACA0012 airfoil profile was extruded from the two dimensional mesh, obtaining the GLC305 profile through the mesh morphing of the 3D NACA0012 geometry, following the same practice already adopted for the two dimensional case. Final 3D grids are composed by 98000 hexaedral cells and 110825 nodes each.

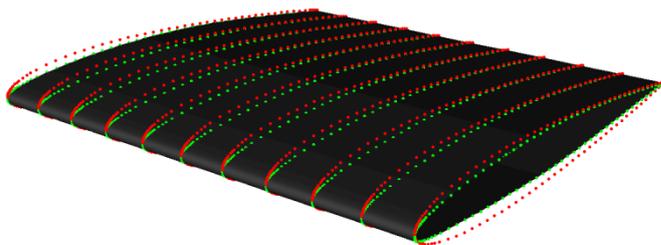


Figure9 clean GLC305 airfoil profile (green dots) obtained by means of mesh morphing of a NACA0012 wing profile (red dots).

Considering that there is a profile symmetry along the third dimension the ice shape – the result of an ice accretion model – will remain unchanged along the span. Being the 2D and 3D results identical, CFD analysis weren't carried, but accretion was reproduced anyway to demonstrate the 3D mesh update capability. Ice build-up was simulated linear, and completed for the same amount of steps needed for the 2D case. The time employed by RBF Morph raised from 0.1 s for the 9800 cell 2D problem with 200 source points to 6 s

for the 98000 cell 3D case with 2200 source points. In Figure 10 a morphed 3D profile at final step of accretion is shown with a section of the volume mesh.

To finally test RBF Morph in a more challenging environment and to prove its ability to update the mesh in a complex three dimensional context, was carried a further benchmark with the ice build up evolving in the three directions, achieving the variable accretion along the span imposing two different ice shapes at the wing extremities. Final results are shown in Figure 7 and 8.

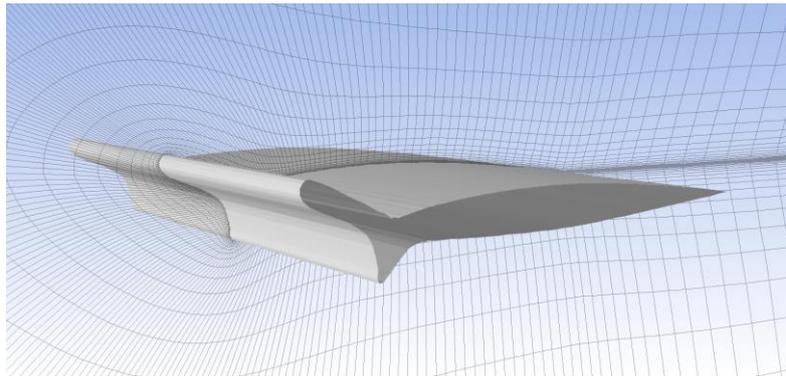


Figure10 morphed 3D profile at final step of accretion

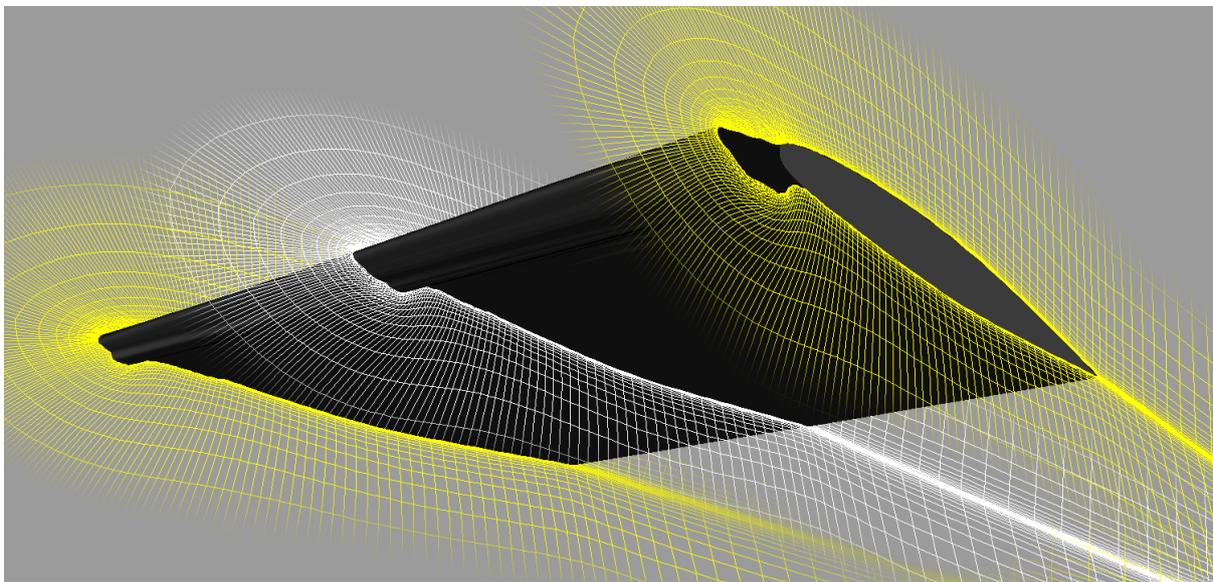


Figure11 Mixed accretions and grid sections at 0, 0.5 and 1 span.

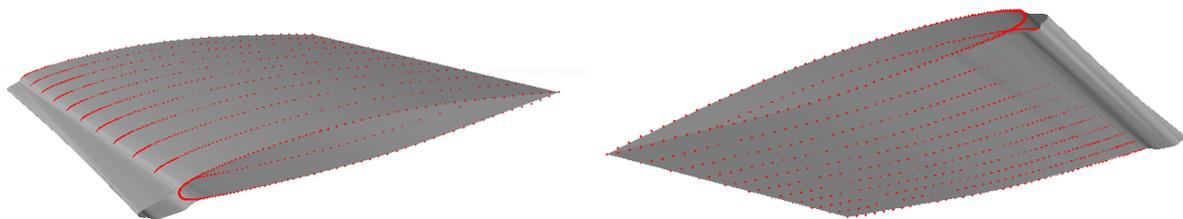


Figure12 morphed geometry of the completely accreted ice with source points in the original position

Conclusions

In this paper an icing application of mesh morphing by means of Radial Basis Functions is presented. Being able to regenerate a modified grid in the shortest amount of time is critical when dealing with an ice accretion model, as it is required cyclically at every step by the accretion model itself.

RBF morphing provides the ability to morph the wing profile assuring both speed and quality, allowing to define the displacement of the interested nodes only.

Integrating an RBF morpher into the icing analysis process, allows to optimize efficiently the workflow in terms of both time and quality.

Acknowledgments

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