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A novel Hermite Taylor least square based meshfree framework with adaptive upwind scheme for two dimensional incompressible flows. (English) Zbl 1390.65131

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Summary: A new meshfree framework based on Hermite Taylor least square finite difference method is proposed. The conventionally used least square finite difference (LSFD) scheme with ghost point method for Neumann boundary conditions is known to have shortcomings especially for irregular nodal distributions. In this work, the performance of the LSFD scheme is augmented by incorporating a novel Hermite Taylor least square (HTLS) method for easy and efficient implementation of the Neumann boundary conditions. The method is initially validated by solving a Poisson equation with both Dirichlet and Neumann boundary conditions. With its promising numerical performance, the method is extended to the full Navier-Stokes equations in two dimensions. An innovative adaptive upwind scheme is adopted to handle the convective terms in the momentum equations by modifying the support domain in the upstream direction. By using a modified Euclidean distance function according to the local flow direction and the value of parameter that controls the convection effect (mesh Peclet number), the local support domain can be shifted towards the upstream direction thereby naturally incorporating the upwind effect while computing the coefficients for the LSFD method. The Navier-Stokes equations are solved in a primitive variables (velocity and pressure) approach by using a first order semi-implicit projection method. In order to validate the developed framework, three flow problems (lid driven cavity, channel flow and flow over a circular cylinder) are considered. All of these problems are well documented because of their benchmarking relevance. It is observed that the new framework produces results which match qualitatively as well as quantitatively with earlier established theory and observations and hence demonstrate its ability to successfully simulate flows of practical interest in an entirely meshfree approach.

MSC:

65N06 Finite difference methods for boundary value problems involving PDEs

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meshfree methods; LSFD; Hermite Taylor least square; adaptive upwind

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References:

[1] Monaghan, J. J., An introduction to SPH, Comput Phys Commun, 48, 88-96, (1988) · Zbl 0673.76089

[2] Liu, TW. K.; Jun, S.; Zhang, Y. F., Reproducing kernel particle methods, Int J Numer Methods Fluids, 20, 1081-1106, (1995) · Zbl 0881.76072

[3] Belystchko, T.; Liu, Y. Y.; Gu, L., Element-free Galerkin methods, Int J Numer Methods Eng, 37, 229-256, (1994) · Zbl 0796.73077

[4] Atluri, S. N.; Zhu, T., New meshless local Petrov-Galerkin (MLPG) approach in computational mechanics, Comput Mech, 22, 2, 117-127, (1998) · Zbl 0932.76067

[5] Kansa, E. J., Multiquadrics - a scattered data approximation scheme with applications to computational fluid-dynamics - I, Comput Math Appl, 19, 8/9, 127-145, (1990) · Zbl 0692.76003

[6] Kansa, E. J., Multiquadrics - a scattered data approximation scheme with applications to computational fluid-dynamics - II, Comput Math Appl, 19, 8/9, 147-161, (1990) · Zbl 0850.76048

[7] Ding, H.; Shu, C.; Yeo, K. S.; Xu., D., Development of least-square-based two-dimensional finite difference schemes and their application to simulate natural convection in a cavity, Comput Fluids, 33, 137 154, (2004) · Zbl 1033.76039

[8] Sandnes, P. G., Meshfree least square-based finite difference method in CFD applications [master thesis], (2011), Faculty of Engineering Science and Technology, NTNU

[9] Penney, D. E.; Edwards, C. H., Elementary linear algebra, (1988), Prentice-Hall

[10] Batina, J. T., A gridless Euler/Navier-Stokes solution algorithm for complex two-dimensional applications, technical report TM-107631, (1992), NASA

[11] Liszka, T.; Orkisz, J., The finite difference method at arbitrary irregular grids and its application in applied mechanics, Comput Struct, 11, 83-95, (1980) · Zbl 0427.73077

[12] Chinchapatnam, P. P.; Djidjeli, K.; Nair, P. B., Meshless RBF collocation for steady incompressible viscous flows, (Proceedings of the AIAA 36th fluid dynamics conference and exhibit, AIAA paper 2006-3525, San Francisco, CA, (June 2006)) · Zbl 1125.76053

[13] Ramos, A, Development of a meshless method to solve compressible potential flows [M.S. thesis], (2010), California Polytechnic State University San Luis Obispo

[14] Kuhnert, J.; Tiwari, S., Grid free method for solving the Poisson equation. nr. 25, (2001), Berichte des Fraunhofer ITWM

[15] Balay S, Buschelman K, Eijkhout V, Gropp WD, Kaushik D, Knepley MG, McInnes LC, Smith BF, Zhang H. PETSc webpage, http://www.mcs.anl.gov/petsc; 2009.

[16] Chan, Y. L.; Shen, L. H.; Wu, C. T.; Young, D. L., A novel upwind-based local radial basis function differential quadrature method for convection-dominated flows, Comput Fluids, 89, 157-166, (2014) · Zbl 1391.76529

[17] Gu, Y. T.; Liu, G. R., Meshless techniques for convection dominated problems, Comput Mech, 38, 171-182, (2006) · Zbl 1138.76402

[18] Chorin, A. J., A numerical method for solving incompressible viscous flow problems, J Comput Phys, 2, 12-26, (1967) · Zbl 0149.44802

[19] Ghia, U.; Ghia, K. N.; Shin, C. T., High-re solutions for incompressible flow using the Navier-Stokes equations and a multigrid method, J Comput Phys, 48, 387-411, (1982) · Zbl 0511.76031

[20] Grove, A. S.; Shair, F. H.; Petersen, E. E.; Acrivos, A., An experimental investigation of the steady separated flow past a circular cylinder, J Fluid Mech, 19, 60-80, (1964) · Zbl 0117.42506

[21] Dennis, S. C.R.; Chang, G. Z., Numerical solutions for steady flow past a circular cylinder at Reynolds numbers up to 100, J Fluid Mech, 42, 471-489, (1970) · Zbl 0193.26202

[22] Nieuwstadt, F.; Keller, H. B., Viscous flow past circular cylinders, Comput Fluids, 1, 59-71, (1973) · Zbl 0328.76022

[23] McDonald, R. A.; Ramos, A., Hermite TLS for unstructured and mesh-free derivative estimation near and on boundaries, (Proceedings of the 2011 AIAA aerospace sciences meeting, (2011)), submitted for publication

[24] Sridar, D.; Balakrishnan, N., An upwind finite difference scheme for meshless solvers, J Comput Phys, 189, 1-29, (2003) · Zbl 1023.76034