Adaptive Mesh Refinement Method Suitable for CFD Analysis of Wind Environment around Buildings

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ABSTRACT

In order to generate effective grid for CFD analysis of wind environment around buildings in urban area, we newly develop non-uniform type adaptive mesh refinement method (NUAMR). Different from the conventional uniform type AMR (UAMR), NUAMR won't smooth mesh outside a windward stream tube of a target region. By comparing overall performance between UAMR and NUAMR, we reveal NUAMR method's advantage as listed below: 1) NUAMR method and UAMR method have almost same accuracy in wind velocity ratio around a high-rise building. 2) NUAMR method can automatically generate computational cost-effective mesh that has much smaller number of cells than UAMR method creates.

1. INTRODUCTION

Our previous study (Imano et al. 2007.7) reveals that adaptive mesh refinement (AMR) can automatically generate a cost-effective mesh for CFD analysis of wind environment around a single low-rise building. However this type of ordinary AMR method would be less effective than manual mesh generation performed by CFD expert if we simply apply that method for CFD analysis of wind environment around many buildings. Because CFD expert usually refine mesh finely only inside an important region which is thought to have high possibility for affecting the wind environment around the target building, on the other hand the ordinary AMR refine mesh finely not only inside the important region but also around all buildings. In order to avoid this defect of AMR, we newly develop non-uniform type adaptive mesh refinement method (NUAMR).

2. NON-UNIFORM TYPE ADAPTIVE MESH REFINEMENT

In this study we define *target region* as a region where detail assessment of wind environment is needed in a calculation domain of CFD. Fluid flow outside a windward stream tube passing through the target region is considered to have a weak influence on the wind environment in the target region. Therefore it will be efficient to subdivide coarsely outside the windward stream tube as shown in Figure 1. Identifying location of the stream tube can be performed automatically by using previous results of flow field obtained in the AMR process. The following is an outline of this method.

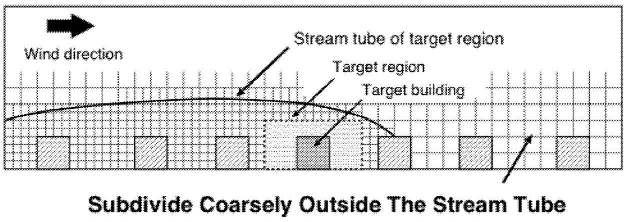


Figure 1: Idea of non-uniform type adaptive mesh refinement

2.1 Detecting the location of the stream tube

Detecting the location of the stream tube could be carried out by conventional particle tracing in theory, however we may have to handle huge number of particles in order to capture the location of the stream tube inside small spaces between neighboring buildings smoothly and almost entirely. Therefore solving the transport equation for a passive scalar is applied to detect the location of the stream tube roughly as described below.

Now we consider that a passive scalar is generated uniformly inside the target region as shown in Figure 2. The transport equation of the passive scalar can be solved with using a previous flow field obtained in the AMR process. We can regard the regions where the solved passive scalar is larger than a presetting threshold as a leeward stream tube. Similarly we can roughly obtain a windward stream tube if we solve the transport equation of the passive scalar with the reversed velocity field. The threshold used in this study is volume average plus standard deviation of the calculated passive scalar field.

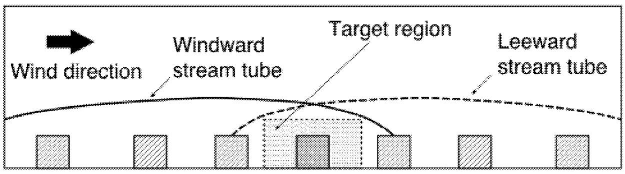


Figure 2: Stream tube of target region

2.2 NUAMR procedure

NUAMR method consists of the following steps.

1. Solve the problem on the available mesh.
2. Reverse the obtained velocity field and solve the transport equation of a passive scalar with generating source uniformly inside the target region.
3. Regions where the solved passive scalar is smaller than a threshold are regarded to be outside the windward stream tube.
4. Estimate the discretisation error by using the Residual Error estimate (Jasak, 2001) (Imano, 2007.1).
5. Refine regions where the estimated error is larger than a threshold. The threshold used in this study is volume average plus standard deviation of the error field.
6. Refine regions where the local jump in the cell size is larger than one. This smoothing procedure is based on *1-irregular* rule (Jasak, 1996).
7. Refine regions where number of split faces exceeds one. We define this smoothing rule as *1-split-face* rule (Imano, 2007.7). This is applied for all regions in UAMR method, while it is applied for regions inside the stream tube in NUAMR method.
8. Map the previous solution to the new mesh and use it as an initial guess.
9. Repeat from step 1 until the number of cycles reached the presetting limit. In this study the limit is two.

3. APPLICATION OF NUAMR

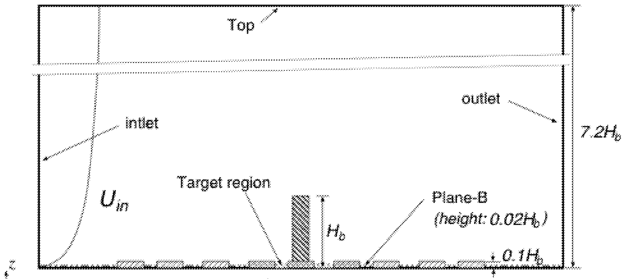
We apply the NUAMR method for a benchmark test case; A high-rise building in city blocks (Yoshie, 2005). This test case was investigated by the "Working Group for Preparation of Wind Environment Evaluation Guide line base on CFD" organized by the Architectural Institute of Japan.

3.1 Calculation conditions

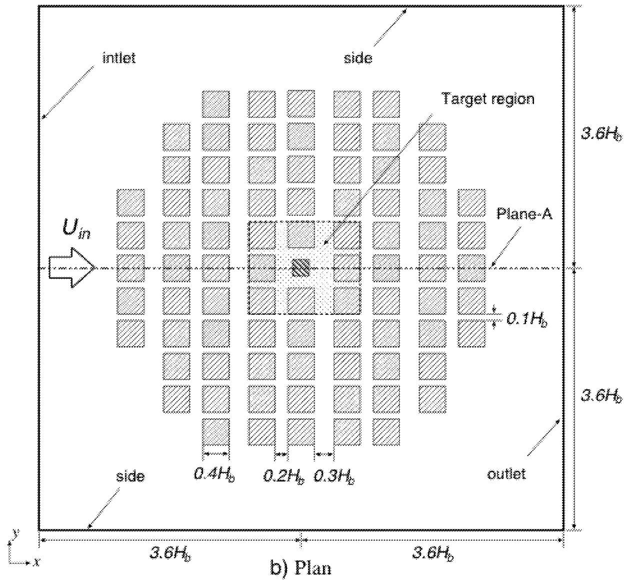
Calculation conditions and geometry of this case are shown in Table 1 and Figure 3. A main purpose of this benchmark is to predict wind environment at pedestrian level around the high-rise building, so we locate a target region in a shaded region as shown in Figure 3. The starting mesh is shown in Figure 4. The finest mesh shown in Figure 5 was created manually in order to get a precise solution for this case.

Table 1: Calculation conditions

CFD code	OpenFOAM (Weller, 1998)
Calc. Domain	$7.2H_b$(x), $7.2H_b$ (y), $7.2H_b$ (z)
Inlet	*U, k*: Interpolate from exp. ε: calculate under $P_k=\varepsilon$
Top, outlet, side	Zero gradient
Ground, wall	Logarithmic law
Turbulence model	Standard *k*-ε
Adv. Scheme	TVD with van Leer limiter
Coupling algorithm	SIMPLE
Number of cells (Min cell width)	Initial: 41,000 (H_b /20) Finest: 3,400,000 (H_b /160)



a) Section



b) Plan

Figure 3: Geometry of this case

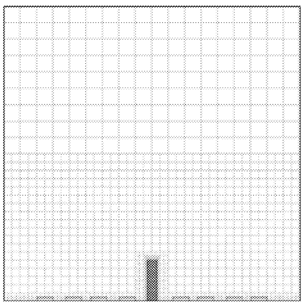


Figure 4: Starting mesh

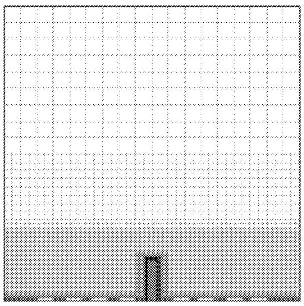


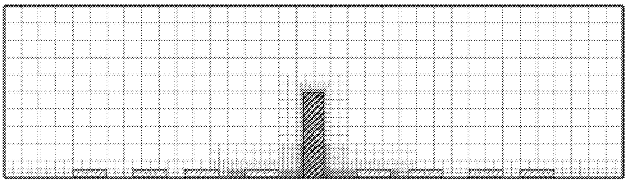
Figure 5: Finest mesh

3.2 Calculation cases

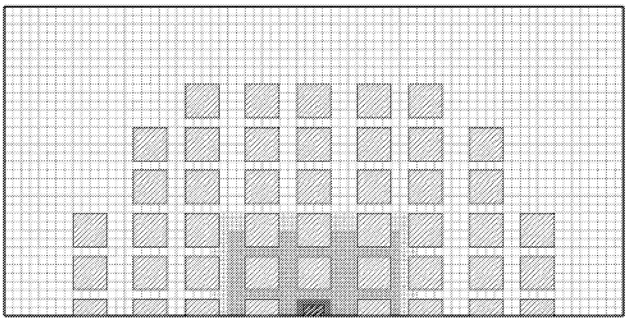
Table 2 shows the calculation cases. Case UAMR uses UAMR method that applies *1-split-face* rule for entire region. Case NUAMR uses NUAMR method that applies the rule only for regions inside the windward stream tube of target region. Case NUAMR-Bi is similar to case NUAMR but it applies the rule for not only the windward but also the leeward stream tube. Case Manual uses mesh refined near the target region manually as shown in Figure 6.

Table2: Calculation cases

Case name	Apply 1-spit-face rule outside the stream tube of the target region	The stream tube of the target region
UAMR	Yes	N/A
NUAMR	No	Windward
NUAMR -Bi	No	Both windward and leeward
Manual	Refine mesh near the target region manually	



(a) On Plane-A



(b) On Plane-B

Figure 6: Mesh in case Manual

3.3 Stream tube of the target region

Figure 7 shows calculated velocity vector field. Figure 8 and 9 show the passive scalar field obtained in case NUAMR and case NUAMR-Bi respectively. We regarded the region with gray or black color as the stream tube, because the solution of the scalar is larger than the threshold there. Although a height of the target region is considerably low as $1/20H_b$, it is found that the stream tube exists widely in the calculation domain.

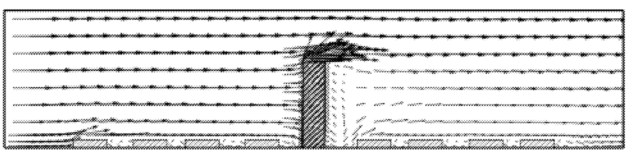
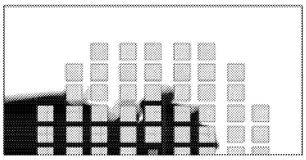
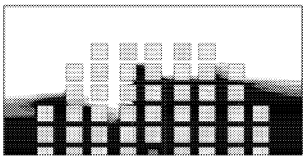


Figure 7: Velocity vector on Plane-A

(a) On Plane-A *(a) On Plane-A*





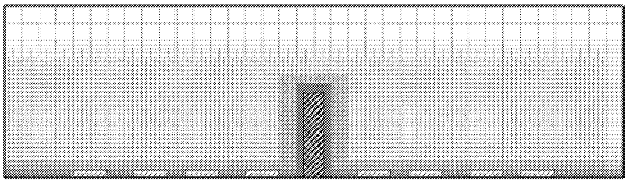
(a) On Plane-B *(a) On Plane-B*

Figure 8: Stream tube in case NUAMR

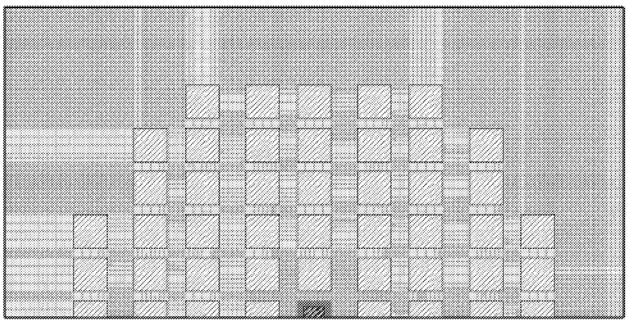
Figure 9: Stream tube in case NUAMR-Bi

3.4 Generated meshes

Figure 10-12 show final meshes generated in each case. In case UAMR most of regions under a height of 1.4H_b were refined uniformly and smoothly due to the 1-split-face rule. In case NUAMR regions inside the windward stream tube were refined smoothly in the same way as case UAMR. One other hand regions outside the windward stream tube were refined finely near around the low-rise buildings and in the wake region of the high-rise buildings, but these regions are not too much smooth like case UAMR. In case NUAMR-Bi regions inside the leeward stream tube were refined finely in addition to the windward stream tube.

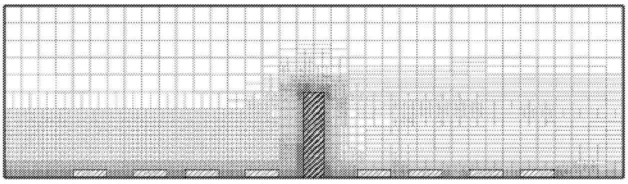


(a) On Plane-A

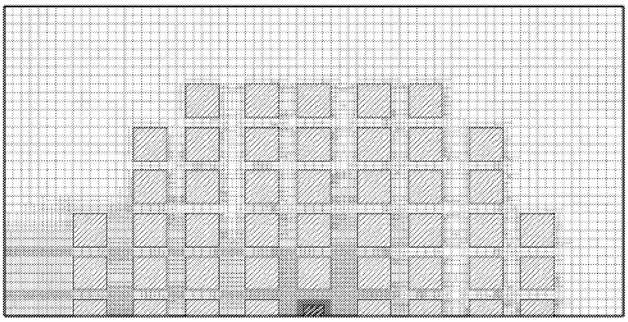


(b) On Plane-B

Figure 10: Generated mesh in case UAMR

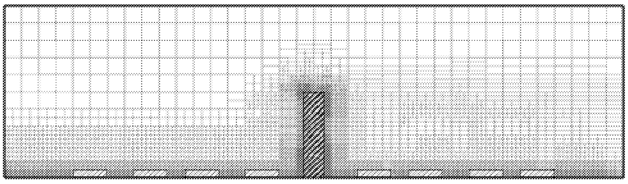


(a) On Plane-A

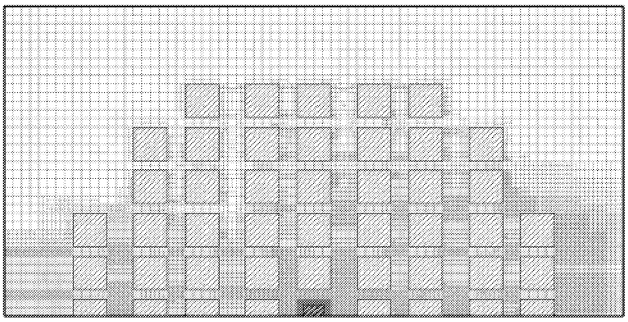


(b) On Plane-B

Figure 11: Generated mesh in case NUAMR



(a) On Plane-A

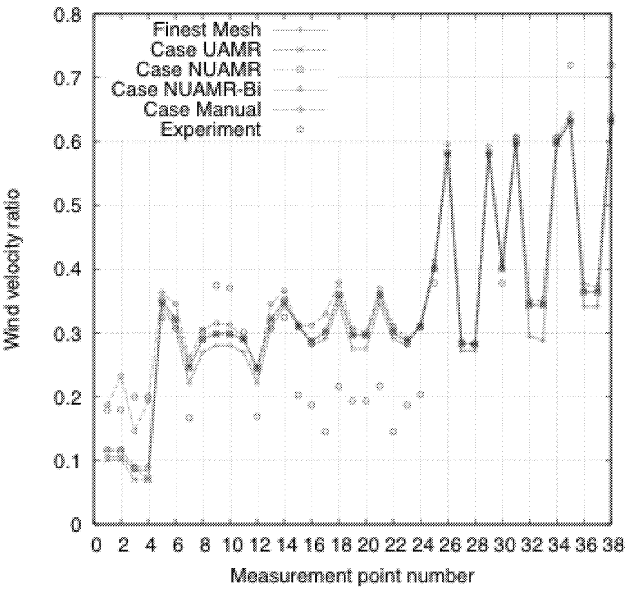


(b) On Plane-B

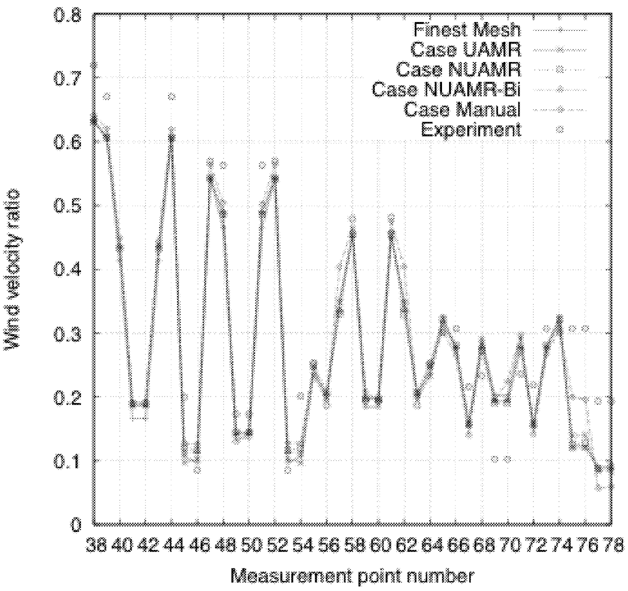
Figure 12: Generated mesh in case NUAMR-Bi

3.5 Comparison of wind speed ratio

The calculation results of wind speed ratio around the high-rise building in each case are compared in Figure 13. This figure also includes the experimental results measured by anemometer with split film probe in a wind tunnel test (Yoshie, 2005). The measuring points are shown in Figure 14. The results among case UAMR, case NUAMR and case NUAMR-Bi give good agreement with each other. On the other hand there are large differences at some measuring points between case Manual and above mentioned three cases. The CFD analysis results underestimate or overestimate the experimental results even if we use the finest mesh, however the reason may be because we the RANS model as turbulent model in CFD analysis, not the LES model which can reproduce the vortex shedding behind the high-rise building (Yoshie, 2005).



(a) Windward side of the high-rise building



(b) Leeward side of the high-rise building

Figure 13: Comparison of wind speed ratio at measuring points

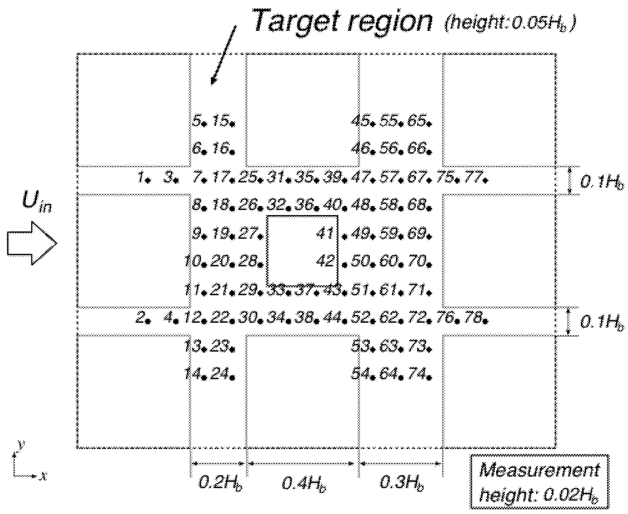


Figure 14: Measurement points of velocity vector in the wind tunnel experiment

3.6 Comparison of overall performance

Table 3 shows the number of cells in the generated mesh of each case. It also contains coefficient of determinations, i.e. R-squared, about the wind velocity ratio between the finest mesh and each cases. The number of cells in case NUAMR is as small as 1/4.6 of that of case UAMR, while the R-squared is almost same as case UAMR. Case NUAMR-Bi generates larger cells than case NUAMR, however the R-squared is same as case NUAMR. Although the number of cells in case Manual is considerably small as 1/16 of that of case UAMR, the R-squared in this case is worse than other cases. If we refine mesh more widely around the high-rise building, we could improve the correlation, however wide isotropic refinement may cause drastic increase in cells. Therefore it can be conclude that case NUAMR is better than other cases in this study.

Table 3: Number of cells in final mesh of each cases and R-squared value about ratio of velocity in those cases

Case name	No. of cells [x10^5]	Ratio of no. cells	R-squared about wind velocity
UAMR	13	1	0.990
NUAMR	2.9	1/4.6	0.989
NUAMR-Bi	3.9	1/3.4	0.989
Manual	0.85	1/16	0.943

4. CONCLUSIONS

We newly develop non-uniform type adaptive mesh refinement method (NUAMR) suitable for CFD analysis of wind environment around buildings in urban area. As the result of the comparison among NUAMR method, the ordinary uniform type AMR (UAMR) method and the conventional manual meshing method, we reveal NUAMR method's advantage as listed below.

1. NUAMR method and UAMR method have almost same accuracy in important CFD results such as wind velocity ratio around a target high-rise building.
2. NUAMR method can automatically generate computational cost-effective mesh that has much smaller number of cells than UAMR method generates.

ACKNOWLEDGEMENT

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