Obstacle Detection and Avoidance Algorithm for Autonomous Mobile Robot using 2D LiDAR

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Abstract— **The autonomous mobile robot play vital role in military applications and can perform difficult and dangerous tasks like neutralizing explosives, walking through minefields, rescue life of soldiers in risky situations. The advancement of research in field of autonomous robot needs higher degree of automacy and is more challenging in unknown terrain. The implementation of system requires extortionate perception of its surroundings to safely navigate in an unstructured environment. So, accurate Obstacle Detection and Avoidance technique is prime focus in field of mobile robot. This paper proposes efficient obstacle detection and avoidance model based on 2D LiDAR for autonomous mobile robot. The proposed method extracts spatial information from laser point-cloud using segmentation and clustering methods. The Convex hull algorithm is utilized to identify accurate geometrical structure of obstacle. This method also generates forward orientation angle using principal of optimal cost function and visibility graph path planning method is employed to establish optimal route to destination. The proposed obstacle detection and avoidance method utilized simple mathematical model and efficiently achieved good real time performance. The reliability of proposed model is tested on MATLAB simulation platform.**

Keywords—2D LiDAR ;obstacle detection ;obstacle avoidance; mobile robot;convex hull;segmentation;clustering

I. INTRODUCTION

A fully autonomous mobile robot acts as a stand-alone system. It has ability to gain knowledge about the environment by using sensor perception, represent this knowledge to provide a map of the environment they have explored with obstacles or hurdles clearly identified, and plan non-collision route to safely navigate through its operating environment. An autonomous robot intended for military applications can perform tasks from searching to transportation and rescue to attack [1].

The implementation of system requires understanding of its surrounding terrain to navigate safely, so accurate Obstacle Detection and Avoidance is most important in field of mobile robotics. To meet this requirement, we need to identify the sensors for Obstacle Detection that would be the best for an application. In this work LiDAR is used for sensing. LiDAR is active emergent remote sensing technology, configured as range measurement sensor that repeatedly transmits pulse of light using rotating beams at constant rate and computes the distance between the target and itself with high accuracy. By repeating this in quick succession, the device builds up a complex distance 'map' of the operating surroundings around it using surface it is measuring. LiDAR are of two types 2D and 3D .2D have no depth information and flattened with 2D space and while 3D gets heights information generating massive amount of point cloud data resulting in very high computational cost and has higher price than 2D LiDAR [7-9].

The Obstacle Detection is primary requirement of autonomous robot. An essential part of obstacle detection is to extract spatial information through sensor perception. The explored surrounding of robot depends upon field of view of sensor used for detection. The obstacles are of two types [2] Positive obstacles that stand above ground with positive height and Negative obstacles that stand below ground with negative height.

In robotics obstacle avoidance is task of satisfying some control objective subject to non-collision position constraints. Good performance of obstacle avoidance is the basic premise of robot on a task. It determines robots current travelling direction to reach to destination location without any collision. Efficient path planning along with obstacle avoidance method assures safe navigation. The Obstacle Avoidance technologies are categorized as Global obstacle avoidance utilizing known environment information and Local obstacle avoidance based on sensors. The global path planning helps to navigate from source to target locations while local path planning with obstacle detection and avoidance helps to do it safely. The paper focuses at local obstacle avoidance approach based on 2D LiDAR sensor [3].

The paper focuses on positive obstacle detection and local obstacle avoidance based on 2D UTM-30LX. The LiDAR measurements are used to identify spatial structure of obstacle. The proposed method is based on segmentation of point cloud data employed to reduce processing time, followed by clustering. The key contribution of this work is exact mapping of geometrical structure of obstacle using convex hull algorithm. This algorithm uses polar angle method and represents structure of obstacle in terms of polygon increasing efficiency of visibility graph path planning algorithm and obstacle avoidance .The effectiveness of proposed model is verified on MATLAB simulation platform.

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II. RELATED WORK

Extensive research is done in field of autonomous mobile systems. Many obstacle detection and avoidance algorithms have been proposed in the literature for robotics safe navigation that allows the robot to reach its target without colliding with any obstacles that may exist in its path.

The different technologies currently available for passive and active range sensing and their application in robotic is discussed in paper [2] .The Paper throw light on range sensing technologies used in robotics, the factors that can impact are dynamic behavior of robotic system affecting speed of data acquisition, robot platform used for integration of sensors and environmental conditions in which robot act. Some of the mostly used sensor systems [1-3] include computer vision systems using a camera, RADAR (Radio Detection and Ranging) systems, ultrasonic imaging systems and LIDAR systems. LiDAR sensor is most suitable for military application due to advantage of large range, high precision and fast sweep frequency and works best for positive as well as negative obstacles [4-6].

The geometrical character based negative obstacle detection technique for unmanned ground vehicle is proposed in [4]. The width and upside of ditch are considered as feature and SVM classifier is used .The proposed novel set up utilized three 3D LiDAR HDL-32E proved efficient to reduce blind region around vehicle and improved density of scan lines and outperformed drawbacks of traditional setup which used only one 3D LiDAR.

The importance of segmentation is highlighted in paper [10]. It had also discussed three commonly used methods for segmentation along with comparison chart. It proves that segmentation is a most essential step to improve computation.

III. PROPOSED WORK

The main objective behind this work is to achieve good real time performance and improve accuracy of obstacle detection and avoidance module targeted for autonomous robotic systems designed for military applications.

The proposed Obstacle Detection and Avoidance model for autonomous mobile robot is shown in Fig 4. This framework for autonomous mobile navigation is a reactive model. The system is initialized with source and target locations which act as input to system and output is orientation angle generated to navigate robot to target location without colliding with obstacle. The GPS sensor is utilized to determine current position of robot. The 2D LiDAR is used to acquire data of operating environment of robot to explore known bounded region from which distance map is construct of the explored environment. The raw LiDAR data contains occasional noise points so pre-processing is done by applying Median filter which also reduces complexity of clustering. Point cloud is generated to interpret captured information in terms of 2D space. The Obstacle Detection module analyzes the laser-point cloud and distance measurements to detect obstacle and predict its geometrical structure. The visibility graph path planning method along with Obstacle Avoidance logic finds proper angle of orientation and shortest route in light of results of obstacle detection module.

A. LiDAR Module

The LiDAR used is UTM-30LX 2D LIDAR from Hokuyo, measuring range up to 30m. Its horizontal field of view is from - 45º to 225º, angular resolution is set to 0.25º so one scan generates point cloud of 1081 laser points. LiDAR is configured as range measurement sensor utilized to acquire spatial data of operating environment of robot. Distance map of environment within LiDAR field of view is generated.

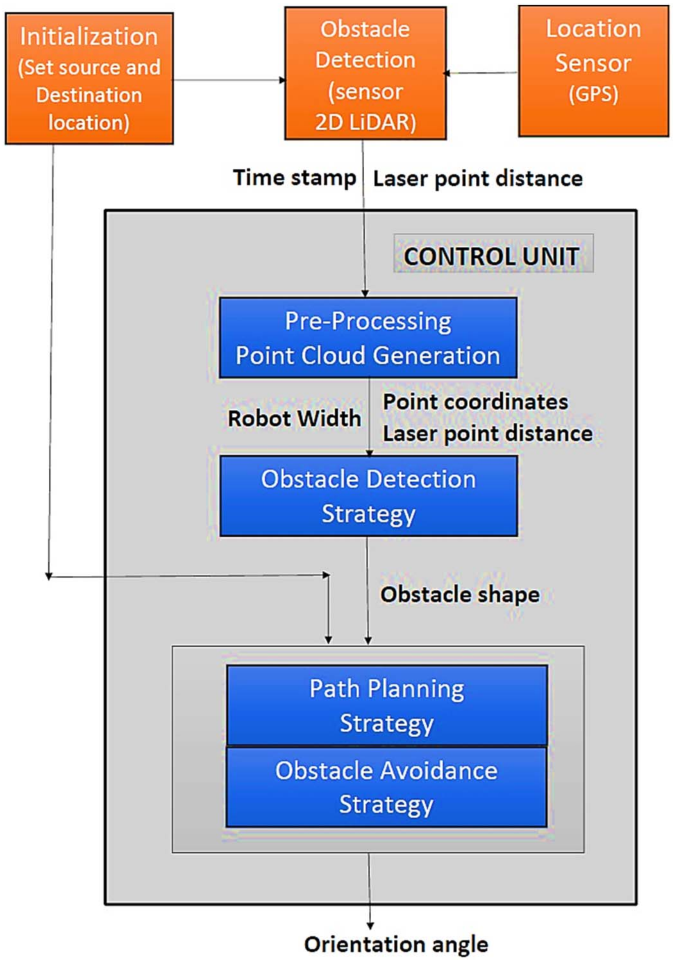

Fig. 1. Operational flow in proposed system

B. Pre-processing

Median Filter

The 3x3 Median filtering masks is applied to laser point cloud. The median of nine values is considered as distance value between robot and laser point to nullify effect of noise. In software implementation vectors are assigned with values of laser points distance measurements. Let t be current time and $D(t,i)$ *be* distance value of laser point i then mask shown in equation 1 is applied to distance data.

$$\begin{matrix} D(t-1,i-1) & D(t-1,i) & D(t-1,i+1) \\ D(t,i-1) & D(t,i) & D(t,i+1) \\ D(t+1,i-1) & D(t+1,i) & D(t+1,i+1) \end{matrix} \quad \textbf{- (1)}$$

C. Point Cloud Generation

Each point in distance map has relative position to LiDAR which can be computed from distance and scan angle value. We can calculate coordinates of each point using equation (2). Let D_i be distance of laser point P_i, $(\boldsymbol{x_i}, \boldsymbol{y_i})$ be position of laser P_i . To get clear view of low obstacles, LiDAR is mounted slightly inclined downwards with sloping angle 12.4º represented by angle a , θ is scanning angle of LiDAR, then Point coordinated can be calculated using equation (2)

$$x_i = D_i * \cos\theta * \cos a$$
$$y_i = D_i * \sin\theta * \cos a \qquad - (2)$$
$$i \in (0, 270)$$
$$\theta \in (-45^{\circ}, 225^{\circ})$$

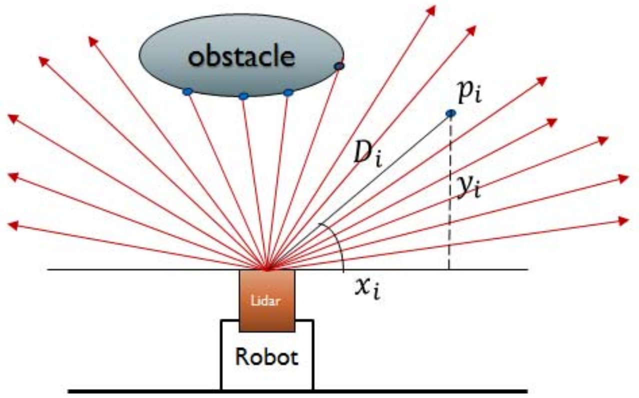

Fig. 2. Laser-point cloud generation

D. Obstacle Detection

The point cloud is generated after pre-processing distance data acquired by LiDAR which serves as input to obstacle detection algorithm. The algorithm extracts planar information from laser-point cloud data. It interprets visible portions of laser-point cloud that are sampled from opaque object in surrounding and construct polygonal representation of visible portions of surface. The steps followed for detection of obstacle are as follows.

1) Segmentation

Segmentation is proposed in this work to improve classification and performance of Obstacle Detection. Segmentation retains only those laser-point cloud data which encounter obstacle, discarding points which never return to robot. For simplicity, in space order first divide incoming LIDAR laser-point cloud data into groups of 1082 laser points. Then segmentation criteria is applied to each point in a group, splitting laser points into N blocks by satisfying criteria for start and end index of block as specified in step 2 of algorithm I.

2) Clustering

The segmentation divides 1082 laser points into N blocks, each containing spatial data of obstacles. To form perfect cluster criteria followed is that Euclidean distance between two consecutive laser points in block is less than width of robot. Split block if distance is more than width of robot and merge two locks if distance between two blocks is less than width. Points are added between merged blocks to make them spatially continuous. The width of robot is enlarged with some clearance value to keep safe distance between robot and obstacle. Thus after clustering we get N blocks such that each block represents obstacle data and distance between two blocks is such that robot can safely pass through them.

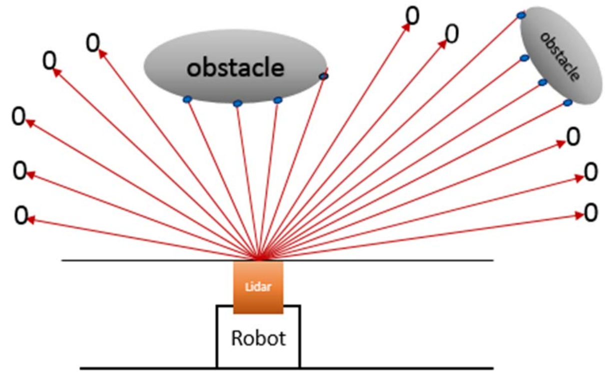

Fig. 3. Block formation using Segmentation

3) Obstacle structure Identification

The laser-point cloud is split into N independent clusters and next step is to determine geometrical structure of obstacle. To map the object boundaries accurately, mathematical representation of obstacle is achieved using Convex Hull algorithm. Graham Scan algorithm based on polar angle is utilized to generate obstacle structure in terms of polygon.

Algorithm I: Obstacle Detection

Input: Laser Distance D(i), Point cloud, width of robot $\boldsymbol{w}$.
Output: Geometrical representation of Obstacle.

Parameters:
Let i be index within block, d_s be distance between two points within same block, d_m be distance between last point $plast$ of previous block and start point $pstart$ of next blocks and f be magnification factor.

1. In space order divide data into groups of 1082 laser points
2. Segment into N blocks satisfying following criteria
   if ((D(i − 1) == 0) && (D(i)!= 0))
   then
     Set starting index of block
   endif
   if (($D(i)$!= 0) && ($D(i + 1)$ ==0))
   then
     Set terminating index of block
   endif
3. Cluster N blocks to satisfy characteristic
   Characteristic: Euclidean distance between two consecutive points in block is less than width of robot
   if ($ds > f * w$)
   then

Split_Block
Increment block count by one
endif
if $(dm < f * w)$
then
Merge_Blocks
Decrement block count by one
Add m points between two blocks with distance value generated using formula

$$\boldsymbol{D(j)} = \boldsymbol{D}(plast) + \boldsymbol{j} * \frac{\boldsymbol{D}(\,pstart) - \boldsymbol{D}(plast)}{\boldsymbol{m}}$$

endif

4. Predict geometrical structure of obstacle in two-dimensional space using Graham scan algorithm
Input: finite set of points
$Q = \{p_0, p_1 \ldots\ldots, p_n\}$ where $p_i = (x_i, y_i)$ and $i > 3$
Constraints: All points must be unique and collinear
Output: convex hull of Q is $CH(Q)$
such that $Q \subset CH(Q)$

E. Obstacle Avoidance

To determine optimal collision free path , robot's travelling direction has to be calculated in terms of orientation angle .The degree of freedom of robot decides configuration space given by two dimensional space and limits of orientation angle. The proposed method assigns $0 - 180°$ angular degree of freedom to robot for obstacle avoidance.

Algorithm II: Obstacle Avoidance
Input: Source and Destination coordinates, Geometrical structure of obstacle.
Output: Orientation angle.

Parameters:
DOF : Degree of freedom
Configuration Space: 2D with three $DOF(x, y, 180)$, destination coordinates (d_x,d_y) and current coordinates of robot (c_x,c_y)

1. Calculate robots optimal travelling angle as θ_t

$$\theta_t = actan(\frac{y_{dest} - y_{robotlocation}}{x_{dest} - x_{robotlocation}})$$

2. Find current travelling direction $\propto_t$,for first scan $\propto_t = \theta_t$
3. Calculate difference $diff = \propto_t - \theta_t$
4. if $(Obstacle\ Detected == No)$
then
if $(diff = 0)\{$orientationangle $= \theta_t\}$
if $(diff > 0)\{$orientationangle $= \propto_t + diff\}$
if $(diff < 0)\{\propto_t = \propto_t - diff\}$
$\propto_t =$ orientationangle
endif
5. if $(Obstacle\ Detected == Yes)$
then

$$\beta_f = tan(\frac{y_{firstpoint} - y_{robotlocation}}{x_{firstpoint} - x_{robotlocation}})$$

$$\beta_l = tan(\frac{y_{lastpoint} - y_{robotlocation}}{x_{lastpoint} - x_{robotlocation}})$$

$\beta = \min\{|\beta_f, \beta_l|\}$
$\beta.x = \beta.x + (robotwidth/2)$.

$$\propto_t = tan(\frac{y_{lastpoint} - y_{robotlocation}}{x_{lastpoint} - x_{robotlocation}})$$

orientationangle $= \propto_t$
endif

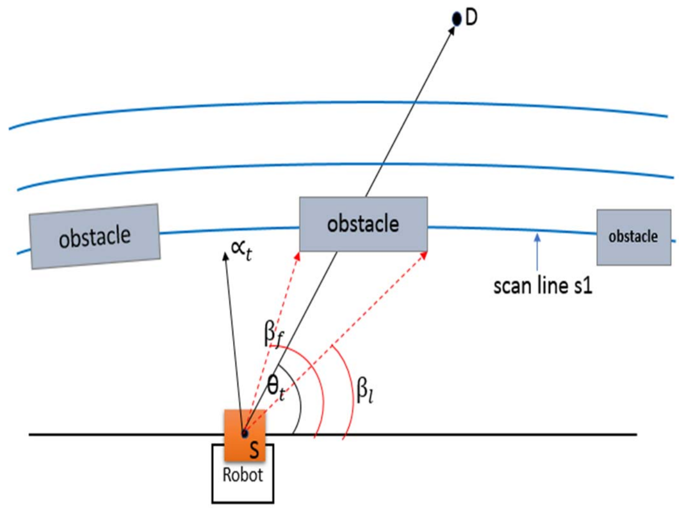

Fig. 4. Determining optimum travelling direction

IV. EXPERIMENTAL RESULTS

To test effectiveness of model, the proposed method is executed on standard dataset and to test validity and reliability simulation is used.

A. Development Environment

The embedded Linux platform with cross compilation is used to implement system. The Intel Core i5 2410M Processor with 64 bit UBUNTU 14.04 LTS Operating System is used as developing computer which act as host. The Raspberry pi 3 Model B single board computer is used to implement the control logic with ARM Cortex-A7 Processor and Raspbian Operating System which act as target computer. The proposed method is developed in Eclipse IDE using C++ language. The gcc-linaro-arm-linux-gnueabihf-raspbian-x64 cross compiler tool chain is used to build bytecode for embedded platform.

B. The Málaga Stereo and Laser Urban Data Set

This is standard dataset which recorded data in realistic urban scenarios using overall eight sensors: one stereo camera, five Laser scanners, one inertial measurement unit and one GPS. The laser scanners used where two SICK LMS and three Hokuyo 2D outdoor LiDAR sensors .The high resolution Stereo camera was utilized to captured images at higher rate i.e. 20fps covering 36.8 kilometres trajectory. Binary and plain text files are provided.
To verify validity of proposed obstacle detection and avoidance method, we have used GPS and Hokuyo UTM-

30LX LiDAR data from standard Malaga dataset. The size of LiDAR range measurements is 1082X1557 along with 1557 time stamps.

C. *Obstacle Detection and Avoidance results*

To test effectiveness of proposed method, standard dataset of UTM-30LX outdoor LiDAR was used. The LiDAR raw dataset containing 1557 scan lines, each containing 1082 laser points was manipulated. It is seen from results of implementation that proposed obstacle detection and avoidance method can effectively filter noise and split point cloud into segments and clusters quickly. The results of pre-processing and laser-point cloud generation are shown in Fig. 5.and Fig. 6 respectively. The convex hull algorithm results are shown in Fig. 7 .The output of convex hull algorithm is set of points which when plotted represented most accurate structure of obstacle.

D. *Simulation Results*

To test validity of proposed method simulation tests were carried out on MATLAB 2012 simulation platform. Simulation scenario is an area of 100m X100m, (0, 0) is the starting point, (100, 100) is the termination point. Setting detection range of LIDAR to be 20m and 30m respectively, a series of obstacles were set up in those tests, and the results of those tests proved that obstacle in the path were accurately detected using convex hull algorithm and robot safely reached target location without any collisions as shown in fig 6.

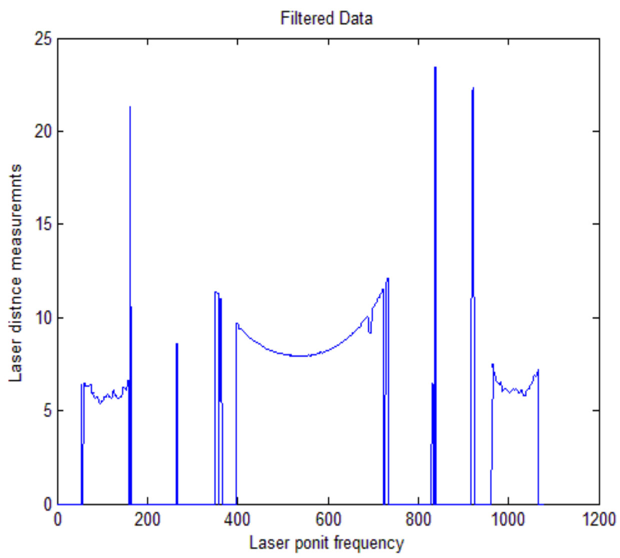

Fig. 5. Median Filtering application on LiDAR distance measurements

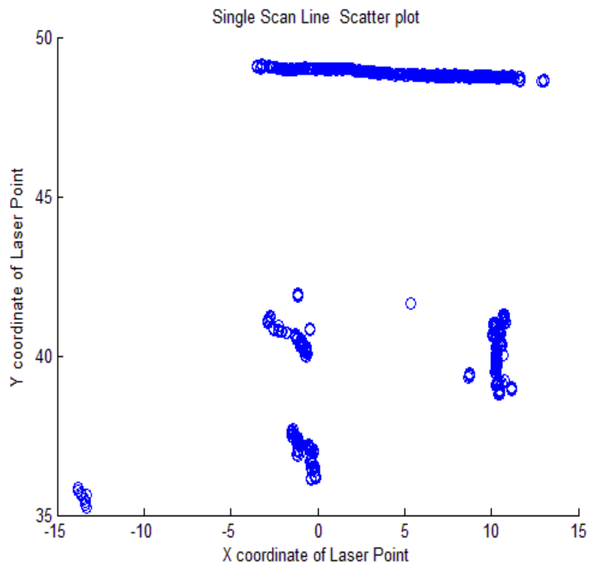

Fig. 6. Laser-point cloud data of LiDAR

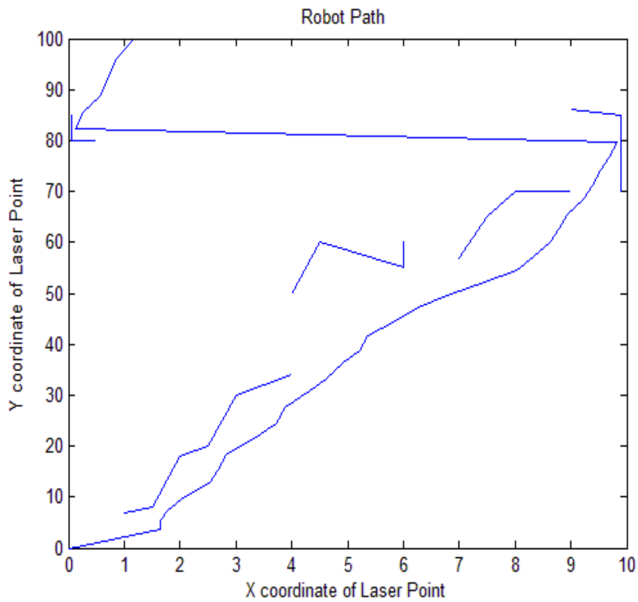

Fig. 7. Robot Path achieved by Algorithm

V. CONCLUSION

The proposed model design for autonomous ground mobile robot, based on Hokuyo outdoor UTM-30LX 2D LIDAR proved efficient in effectively filtering noise, reducing complexity of clustering. The enhancement was seen in processing speed of Obstacle Detection and Avoidance methods due to segmentation. The utilization of convex hull algorithm, to represent obstacle structure in terms of polygon has improved performance of path planning and obstacle avoidance method.

Raspberry pi 3 was used as embedded system to implement logic thus making system more robust, economical and

portable. The simulation results proved reliability and effectiveness of proposed obstacle detection and avoidance model.
The future work will focus on parallel programming of proposed model to improve processing time thus achieving optimal real time performance.

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