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Scanning Camera and Augmented Reality Based Localization of Omnidirectional Robot for Indoor Application

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Abstract

The aim of this paper is to develop an absolute visual localization system of an Omni wheeled robot for indoor navigation. Omni wheeled based robots have omni directional drive capacity. Conventional localization technique like odometry is not suitable for such drives due to wheel slippage. An omni robot platform with 4 omni-directional wheels powered by dynamixel motor and a scanning platform has been developed. We have implemented a localization technique using camera as visual sensor and multiple markers based on 'ArToolKit' an augmented reality application. Various camera related distortion were reduced using 2nd order surface fit of camera calibration data. To increase the accuracy of the system, fusion of results from multiple markers has been implemented. Performance of the proposed localization has been verified by studying different pattern based movement of the system in a test area of 5m X 5m. Novelty of this paper is in development of an omni wheeled robotic wheelchair and proposing a robust absolute visual based localization set up with single camera and multiple fused markers for indoor navigation.

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1. Introduction

Omni wheeled mobile platforms realizing holonomic and omni-directional motion provides improved mobility solutions for application related to indoor navigation, guidance robots, electronic wheelchairs and transporter for geriatric population. Omni-platforms provide flexibility and high manoeuvrability to motion planners and human drivers due to its capacity to move side wise without changing its orientation. This characteristic is very suitable for wheelchairs and personal mobile vehicles which are used in daily life for manoeuvring crowded area at home^{1,2,3}.

Localization techniques are classified in two broad categories which are relative localization and absolute localization. Relative localization calculates robot's position by measuring velocity and yaw angles by encoders fitted with the wheels or through some inertial system. The pose of the robot is updated from a known starting location by

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integrating the sensor measurements over time as the robot moves. Omni wheels have series of rollers connected to the main wheel periphery. This arrangement imparts the holonomic motion but also introduces slip during movement. Due to this, incremental localization cannot be relied alone without the help of an external absolute localization system. In absolute localization, robot's position is calculated by external distance measurement system like ultrasonic positioning system, the global positioning system (GPS), infra-red network systems, RFID systems, Laser based system (LIDAR)⁴, Vision based localization, etc. Choice of any particular localization technique is dependent on speed, accuracy cost, application area, etc.

Vision based localization mainly uses triangulation or trilateration or combination of both algorithms. Most conventional vision based localization utilizes an overhead camera looking at the entire movable area of the robot, and specific colour and shaped markers are mounted on the top of the robot^{5,6}. This type of system, although simple, but suitable for only small sized robot arenas. Large operating area or multiple rooms would require multiple cameras installed, and will increase computational complexity for the processing computer.

In this paper, we present development of a 4 wheeled omni robotic platform and propose a new method for absolute localization based on multiple static augmented reality markers and a 360 degree scanning camera. In this method, we have used multiple augmented reality markers throughout the arena. These markers have different patterns to identify them and their position and orientations are known. Scanning camera registers one or more than one marker at a given point of time and the robot localizes itself with respect to the marker. A non-linear calibration procedure is implemented to calibrate the readings obtained from the markers. Fusing reading of multiple markers accuracy of pose estimation is improved. All localization related computations are done inside an on-board portable computer. There is no need of any additional camera or computing unit anywhere else in the arena. Proposed visual localization set-up is unique in terms of methodology and implementation.

2. System Development

Unlike differential or steering drive, omni drive systems^{7,8,9} does not possess holonomic constraints, allowing motion in both the body axis possible. Moreover, translational movement along any desired path can be combined with a rotation, so that the robot arrives to its destination at the correct angle. Design of a 4 wheel driven Omni Wheel based platform needs special attention. Regardless the surface type, all four wheels should receive equal ground reaction force. Violation of this would result slippage in the wheel having the minimum ground reaction force. This will introduce errors in the odometry process as well as difficulty in close loop path planning¹⁰. To maintain equal GRF on all the wheels, the wheels should be mounted with proper suspension mechanism. To solve this problem in a compact sized robot, we have used leaf-spring mechanism.

The drive system of the omni robot platform is designed with 4 dynamixel MX-28 motor. These motors are extremely compact and light weight (72g), yet provides 3.1N.m torque. The motors have inbuilt PID controller accompanied by 72MHz ARM processor and 12bit contactless absolute encoder. An Intel NUC CPU (2.2GHz, 4GB RAM) is used as on board computation for implementation of localization, navigation and control algorithms. A Logitech C270 web cam is mounted on a dynamixel MX-28 motor to capture image and video for localization and obstacle avoiding. The motor allows full 360deg rotation in the scanning plane. Developed omni robot is shown in Fig.1.

3. Localization Method

Localization by odometry is incremental in nature. An absolute referential system is required to initialize the pose and also for periodic check of any possible deviations from the actual pose. Omni wheel driven vehicles have a lot better mobility than differential drive vehicles, but this imposes much loss in traction. Due to low traction forces and being over actuated, lot of slip occurs between the wheels and ground surface. So a robust absolute localization is required for implementing any closed loop control system of 4 wheel drive omni robots.

3.0.1. ArToolKiT

Augmented Reality Technologies, though not specifically designed to use with mobile robot localization have been advanced a lot due to extensive research in the last decade. A typical Augmented reality system tracks a specially

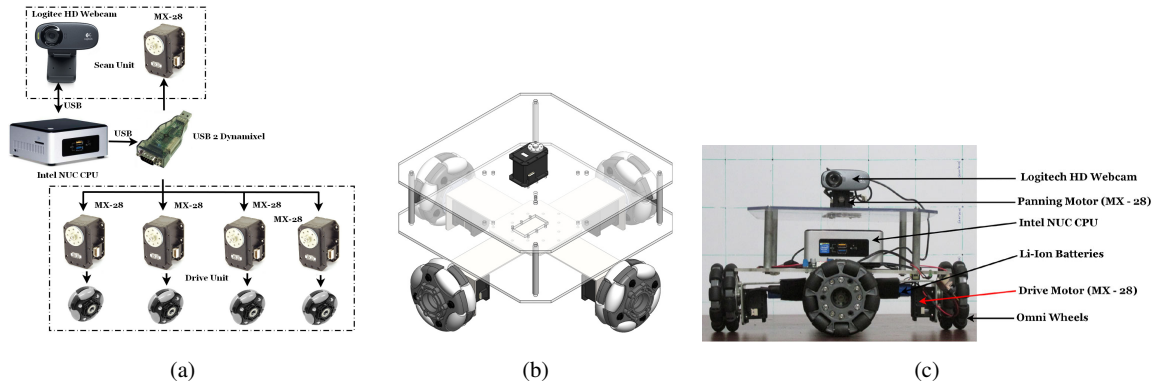


Fig. 1: a) Drives and electronics section of Omni robot b) CAD model of the developed Omni Platform c) Photographic view of the developed system

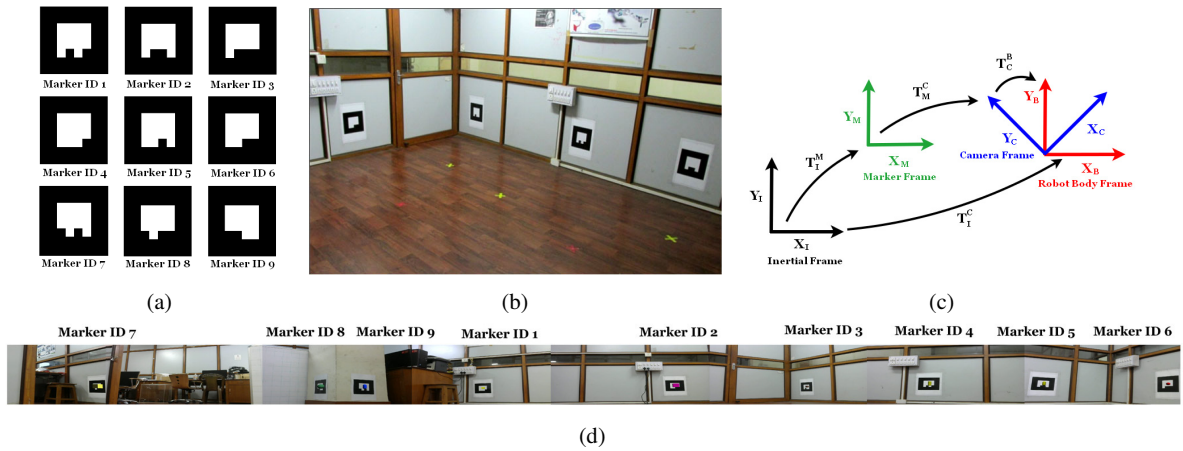


Fig. 2: a) Photo of the markers used. b) Snapshot of the markers mounted in the walls. c) Relation of the co-ordinate frames d) 360 degree panorama showing all the markers in the arena.

designed marker, computes the camera's position and orientation with respect to the environment and overlays some computer graphics generated object into the display device. Markers can be visual^{11,12,13,14,15,16,17} or infrared^{18,19}. Out of several other augmented reality toolkit, ArToolKit²⁰, Siemens Corporate Research (SCR) marker system²¹ are common.

We have used ATK in Unity 4.6 running on Windows 7 platform in an Intel NUC system powered by 2.2 GHz quad core CPU and Intel HD graphics. The omni robot is controlled by a single on-board computer. Logitech HD web cam C270 is used to scan the marker images. Image is acquired from streaming video running at 30 fps.

3.0.2. Arena Setup

Although Augmented Reality technology is pretty much applied for its intended applications, its application in mobile robot localization is not much explored except a few^{22,23}.²² used multiple marker based mobile robot localization. The robot is mounted with several markers on its sides and top. Multiple cameras are installed on the ceiling to cover the robot's operating area.

We have used static markers mounted in the room walls and the camera is embedded into the robot. This type of system is having two major advantages over²². Firstly, there is no need of multiple cameras, thus reducing set up cost of a new environment, secondly all processing is done on a single computer and that is also on-board; so there is

no need of wireless communication between the localization computers and the robot CPU. One corner of the floor is taken as origin of Inertial or global frame. Markers are positioned in the wall (Fig.2 a,b) evenly distributed with a nominal distance of 2m between them. The height at which the markers are placed is determined by the scanning plane of the camera. As we have not implemented any tilting mechanism for the camera, this is an important criteria. The center of the markers are placed 40cm above ground. ArToolKit based system can extract 6 degree of freedom position and orientation information from the markers. But, as we are dealing with localization of a mobile robot in a 2D plane, only translation in x and y axis and rotation about z axis are considered. Marker position and orientation $[x_m, y_m, \theta_m]^T$ with respect to the inertial frame $[x_I, y_I, \alpha_I]^T$ is measured and represented as (Fig.2c)

$$\begin{bmatrix} x_m \\ y_m \\ \theta_m \end{bmatrix} = \begin{bmatrix} \cos \alpha & -\sin \alpha & X_m \\ \sin \alpha & \cos \alpha & Y_m \\ 0 & 0 & 1 \end{bmatrix} \cdot \begin{bmatrix} x_I \\ y_I \\ \theta_I \end{bmatrix} \quad (1)$$

Where X_m , Y_m and α is the relative translation and rotation of the markers with respect to the inertial frame. A 360deg panoramic view of the arena with all the detected marker augmented with different shaped objects is shown in Fig.2d.

3.0.3. System Calibration

ArToolKit based system initially calculates marker's position and orientation with respect to camera's body axis. If $[x_c, y_c, \theta_c]^T$ and $[x_m, y_m, \theta_m]^T$ are position and orientation of the camera and marker with respect to the inertial axis, respectively, we can write

$$\begin{bmatrix} x_m \\ y_m \\ \theta_m \end{bmatrix} = \begin{bmatrix} \cos \theta_r & -\sin \theta_r & x_r \\ \sin \theta_r & \cos \theta_r & y_r \\ 0 & 0 & 1 \end{bmatrix} \cdot \begin{bmatrix} x_c \\ y_c \\ \theta_c \end{bmatrix} \quad (2)$$

$[x_r, y_r, \theta_r]$ are the reading of the position and orientation obtained from the ArToolKit marker.

The relation between true and measured data set do not follow a linear relationship. This non-linearity is due to lens distortion and other camera related parameters. The non-linearity should be mapped before we can use the reading for practical purpose. If we plot the true value of x and y in surface plot with respect to measured x and y value, we obtain the graphs shown in Fig.3. From here it is clear that both the true value of x and y depends upon the measured values of x and y . If X_m and Y_m are the measured values and if X_c and Y_c are the corrected values after the calibration, we can write $X_c = f(X_m, Y_m)$ and $Y_c = f(X_m, Y_m)$. To build the relation, we have used MATLAB surface fit function to express $[X_c, Y_c]$ as 3rd order, two input polynomial function (3),(4). The polynomial co-efficients have been calculated using the calibration data.

$$X_c = px_{00} + px_{10} \cdot X_m + px_{01} \cdot Y_m + px_{20} \cdot X_m^2 + px_{11} \cdot X_m \cdot Y_m + px_{02} \cdot Y_m^2 + px_{21} \cdot X_m^2 \cdot Y_m + px_{12} \cdot X_m \cdot Y_m^2 + px_{03} \cdot Y_m^3 \quad (3)$$

$$Y_c = py_{00} + py_{10} \cdot Y_m + py_{01} \cdot X_m + py_{20} \cdot Y_m^2 + py_{11} \cdot Y_m \cdot X_m + py_{02} \cdot X_m^2 + py_{21} \cdot Y_m^2 \cdot X_m + py_{12} \cdot Y_m \cdot X_m^2 + py_{03} \cdot X_m^3 \quad (4)$$

With (3),(4) the non-linearity problem in the measured location is solved. The calibrated data can be used for the further calculation. Fig.3 shows the fitted surface function along with the data points used to extract the surface.

3.0.4. Scanning

Use of fixed markers and movable cameras impose its own challenges. First of all there is a minimum distance from where the marker can be seen completely. For this reason, the robot cannot approach to near of a wall mounted marker. Secondly, the accuracy of the calculated positions decrease with distance from the markers. Lastly the viewing angle of the camera is 60deg. There may be cases where no markers are detected within this viewing angle, may be blocked by some obstacle. So a 360 deg horizontal scanning is the solution. The camera is mounted on a Dynamixel MX-28 motor (Fig.1c), which receives command from the Unity Software running the ATK program. The camera is rotated by 30 deg in every iteration and picture is taken for processing. The scan interval is kept at half of the camera viewing angle to ensure enough overlapping between consecutive scans. This ensures all the markers are detected atleast once.

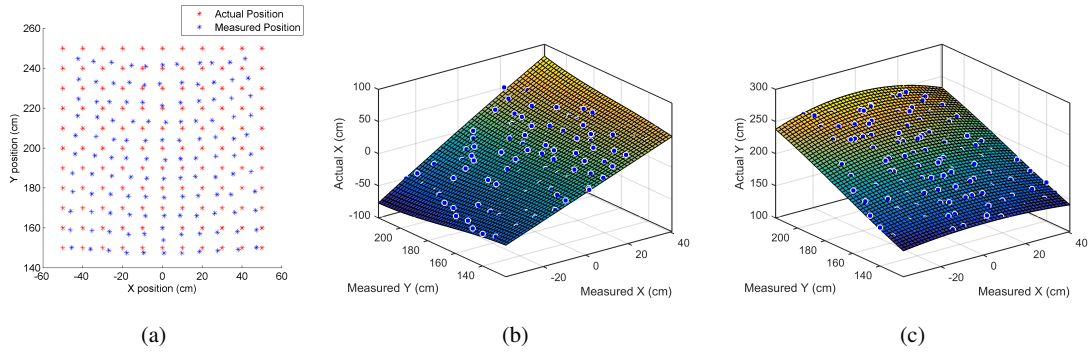


Fig. 3: a) Plot of true location vs measured location b),c) 2nd Order surface fitted with the Measured x and y values.

As the rotational axis of the camera passes through the centre point of the 4 wheels, no translation is present between camera axis and robot body axis. But the camera viewing angle is changed during the scanning. If the scan angle is θ_i at i^{th} scan iteration, we can relate robot's body frame $[x_b, y_b, \theta_b]^T$ with the camera frame $[x_c, y_c, \theta_c]^T$ by using the following equation.

$$\begin{bmatrix} x_b \\ y_b \\ \theta_b \end{bmatrix} = \begin{bmatrix} \cos \theta_i & -\sin \theta_i & 0 \\ \sin \theta_i & \cos \theta_i & 0 \\ 0 & 0 & 1 \end{bmatrix} \cdot \begin{bmatrix} x_c \\ y_c \\ \theta_c \end{bmatrix} \quad (5)$$

Finally we can relate the robot body frame $[x_b, y_b, \theta_b]^T$ to the inertial frame from $[x_I, y_I, \theta_I]^T$ as

$$\begin{bmatrix} x_b \\ y_b \\ \theta_b \end{bmatrix} = \begin{bmatrix} \cos \alpha & -\sin \alpha & X_m \\ \sin \alpha & \cos \alpha & Y_m \\ 0 & 0 & 1 \end{bmatrix} \cdot \begin{bmatrix} \cos \theta_r & -\sin \theta_r & x_r \\ \sin \theta_r & \cos \theta_r & y_r \\ 0 & 0 & 1 \end{bmatrix}^{-1} \cdot \begin{bmatrix} \cos \theta_i & -\sin \theta_i & 0 \\ \sin \theta_i & \cos \theta_i & 0 \\ 0 & 0 & 1 \end{bmatrix} \cdot \begin{bmatrix} x_I \\ y_I \\ \theta_I \end{bmatrix} \quad (6)$$

Here $[X_m, Y_m, \alpha]$ are location of the markers in the arena, $[x_r, y_r, \theta_r]$ are readings returned by ArToolKiT and θ_i is the camera scanning angle. So using (6), robots absolute position and orientation can be calculated from the reading obtained from the ArToolKiT, with respect to a particular marker. The series of transformations and the axes are depicted in Fig.2c. For one complete 360 deg scan, there may be multiple markers detected. Accuracy from all the detected markers during one complete scan depends on the factors like distance from the marker, presence of any obstacle, viewing angle etc.

4. Results and Discussion

For system evaluation, we have tested the performance of the localization system for two cases. A square trajectory and a circular trajectory is generated by set of equations. For a complete cycle of the trajectory, the motion has been paused in 8 segments and a visual localization scan is performed. The Fig.4a shows results obtained from the square trajectory, where, for all the pause locations, readings obtained from each marker along with their average and true location reading (measured by measuring tape) are shown. Fig.4c shows similar reading for the circular trajectory. Fig.4 b,d shows the statistical (mean and variance) distribution of errors obtained from readings of every marker (averaged for all the eight locations) and also error from the mean reading from all the markers. Table.1 shows mean and variance values obtained from both the trajectory.

Localization readings obtained from individual markers show an average error ranging from 2.5cm to 5cm. Fused localization obtained by taking mean of the readings obtained from all the markers shows a significant improvement upon the individual readings. From the Fig.4b and Fig.4c, steeper nature of the Fused distribution curve further confirms that the precision of the localization reading is much improved by taking readings from multiple markers and fusing them.

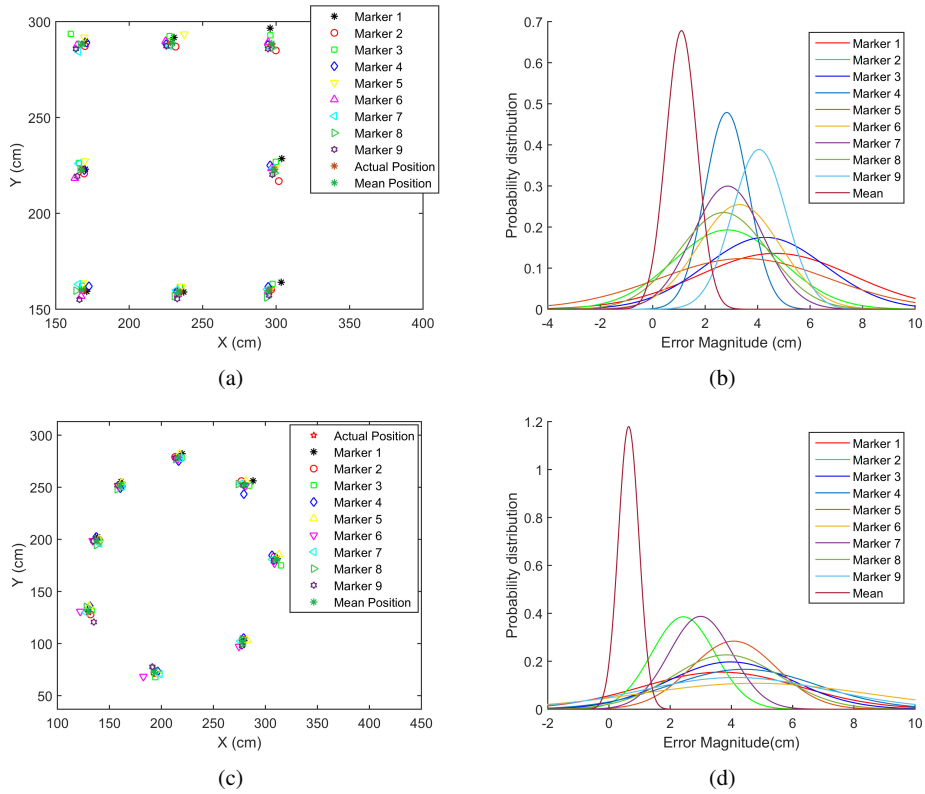


Fig. 4: Relation between True and measured values

Table 1: Mean and variance of the obtained result

Marker ID	μ_1	σ_1	μ_2	σ_2
M1	4.6775	2.9357	3.7799	2.7629
M2	2.8416	2.0675	2.3664	1.0998
M3	4.2854	2.2804	4.0502	2.1702
M4	2.8244	0.8333	4.1626	2.4744
M5	3.4855	3.2340	3.7888	1.2377
M6	3.3034	1.5667	4.2927	3.7277
M7	2.8581	1.3316	3.0372	1.1049
M8	2.7030	1.6950	3.5784	1.7325
M9	4.0569	1.0261	5.6593	7.9197
Fused	0.6433	0.3382	1.0971	0.5885

5. Conclusion

Absolute localization technique is necessary for most of the omnidirectional robots due to their slip problems. In this paper, we present absolute localization techniques on an indigenously developed 4 wheel driven omnidirectional robot platform. Major contribution of the paper lies in implementing a single scanning camera and augmented reality based localization platform. The omni robotic platform and its localization methods are suitable for many indoor

applications including museum guidance systems, automated carts in shopping malls, automated wheelchair systems and many other indoor service robots.

The system requires 5sec to scan the entire 360 deg. During the scan, the robot have to be stationary. This limits the update rate of the system to be little bit slower. But for real life applications, a frequent scan is often not required. Once the robots co-ordinates are initialized by a initial scan, robot can rely on its odometry for localization. But after a certain interval (like 5 minute or more), robot may perform a scan and update its current location to correct any drift caused by the odometer data.

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