

RO-Net: Multimodal Stacked Bidirectional LSTM with Attentions for Indoor Localization using Range-only Measurements

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This material is based upon work supported by the Ministry of Trade, Industry & Energy(MOTIE, Korea) under Industrial Technology Innovation Program. No.10067202, 'Development of Disaster Response Robot System for Lifesaving and Supporting Fire Fighters at Complex Disaster Environment'.

ABSTRACT

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I. INTRODUCTION

SIMULTANEOUS Localization and Mapping(SLAM) is widely used in autonomous vehicles, drones, intelligence field robots, and mobile phone applications. Thus, according to the smart city development plan, several technologies are required in such a way that the demand and the necessity of SLAM increase together. Various kinds of sensors are utilized to SLAM, such as GPS, LiDAR, ultrasonic-based sensor, camera and distance sensor. Especially, trilateration algorithm has been widely incorporated into robotics fields, especially utilized in the indoor environment to estimate the position of an object by distance measurements obtained from range sensors such as UWB, ultrasonic, laser-based beacon sensors [1]–[3] due to the convenience of trilateration that estimates the position of a receiver of range sensors if one only knows range measurement. For that reasons, range-only Simultaneous Localization and Mapping(RO-SLAM) methods are utilized popularly, which not only estimate the position of the receiver of range sensors, but also localize the position of range sensors regarded as features on a map, and studies have been conducted continuously in terms of probability-based approach [4]–[7].

In the meantime, as deep learning age has come [8], various kinds of deep neural architectures have been proposed

for many tasks related to robotics field, such as detection [9]–[11], navigation [12], [13], pose estimation [14], and so on. Especially, recurrent neural networks (RNNs), originated from Natural Language Process(NLP) area [15], have been shown to achieve better performance in case of dealing with time variant information, thereby RNNs are widely utilized such as not only speech recognition, but also pose estimation and localization [14], [16]–[19].

In this paper, we propose a deep learning-based SLAM method by multimodal stacked bidirectional Long Short-Term Memory(multimodal stacked Bi-LSTM) for more accurate localization of the robot. Using deep learning, our structure directly learns the end-to-end mapping between range measurements and robot position. This operation non-linearly maps the relationship not only considering the long-range dependence of sequential distance data by the LSTM, but also using the correlation of the backward information and the forward information of the sequence of each time step by virtue of its bidirectional architecture. Existing RO SLAM needs calibration before filtering, and then, range measurement undergoes outlier rejection, prediction and correction processes are needed. Furthermore, it uses low dimensional data to perform localization, there is a disadvantage that estimation is difficult even if the value deviates slightly from

the model. Therefore, we solve this complex algorithm with end-to-end based deep learning. This system overview is shown in the figure below.

II. RELATED WORKS

In this section, we briefly survey previous researches closely focused on localization using range measurements and case study on utilizing deep learning for localization, especially about applications of Recurrent Neural Networks(RNNs). Finally, we examine how the attention is introduced in the deep learning architectures.

A. LOCALIZATION USING RANGE MEASUREMENTS

Various kinds of sensors have been utilized to localize a object using range measurement sensors, such as GPS, ultrasonic-based sensors, ultra-wideband(UWB) sensors. However, almost distance measured by range measurement sensors are based on Time of Flight(TOF), Time of Arrival(TOA), or Time of Differential Arrival(TDOA).

First, it's very noisy, so it can occur errors easily. Second, the measurement is very ambiguous because each measurement is defined as the probability density of the sensor's potential position. The last problem is that the landmark location estimations may converge to multi-modal densities. Especially, trilateration algorithm has been widely incorporated into robotics fields, especially utilized in the indoor environment to estimate the position of an object by distance measurements obtained from range sensors such as UWB, ultrasonic, laser-based beacon sensors [1]–[3] due to the convenience of trilateration that estimates the position of a receiver of range sensors if one only knows range measurement. For that reasons, range-only Simultaneous Localization and Mapping(RO-SLAM) methods are utilized popularly, which not only estimate the position of the receiver of range sensors, but also localize the position of range sensors regarded as features on a map, and studies have been conducted continuously in terms of probability-based approach [4]–[7].

In robotics fields, Blanco SLAM is a technique for building the map information while localizing the position of the robot while moving. Localization of the SLAM predicts the current position of the robot using the landmark measured by the sensor, and mapping locates the terrain object based on the pose of the robot. Research on this technology has been actively carried out, and researches and techniques have been summarized. In 2006, the *ad hoc* sensor network consisting of range detection beacon was applied to SLAM technology for various ranges. This technology integrates node-to-node measurements to reduce drift and expedite node-map convergence [20] In 2008, the technique to consistently combine the observation information considering the uncertainty was studied through comparing the experimental data with the actual robot and simulation using Ultra Wide-Band (UWB) devices and Rao-Balckwellized Particle Filter (RBPF) [4]. In 2012, a simple and efficient algorithm for position recognition with high accuracy and low computational complexity was researched with ultrasonic sensors [21]. In recent years,

3-dimensional-based SLAM has also been under active research and development. In 2013, a localization mapping approach of a wireless sensor network (WSN) node was studied through a centralized EKF-SLAM-based optimization research [6]. In addition, in 2014, a method of minimizing noise and localizing Unmanned Aerial Vehicle (UAV) by using range-only measurement while simultaneously mapping the position of the wireless range sensors were proposed [22]. SLAM based on range measurement has been continuously researched and developed then applied to various fields. In this paper, we propose a novel technology that applying deep-learning to range-only SLAM that derives accurate range and robot position measurement through in-depth learning.

B. DEEP LEARNING FOR LOCALIZATION

There have been many approaches combining Simultaneous Localization and Mapping (SLAM) with deep learning, aiming to overcome the limitations on SLAM only technique such as difficulty on tuning the proper parameters in different environments and recovering an exact scale. Actually, those researches are showing the superior performance to the traditional SLAM approaches.

One of the popular SLAM techniques with deep learning is CNN-SLAM [23] which takes Convolutional Neural Networks (CNNs) to precisely predict the depth from a single image without any scene-based assumptions or geometric constraints, allowing them to recover the absolute scale of reconstruction. Another approach using deep learning for localization is Deep VO [24] In this method, Recurrent Convolutional Neural Networks (RCNNs) is utilized. Specifically, feature representation is learned by Convolutional Neural Networks and Sequential information and motion dynamics are obtained by deep Recurrent Neural Networks without using any module in the classic VO pipeline.

C. APPLICATIONS OF LSTMS

There are many variations of LSTM architecture. As studies of deep learning are getting popular, various modified architectures of LSTM have been proposed for many tasks in a wide area of science and engineering. Because LSTM is powerful when dealing with sequential data and inferring output by using previous inputs, LSTM is utilized to estimate pose by being attached to the end part of deep learning architecture [17]–[19] as a stacked form of LSTM. In addition, LSTM takes many various data as input; LSTM is exploited for sequential modeling using LiDAR scan data [16], images [14], [17], IMU [25], a fusion of IMU and images [24]. Since existing RO-SLAM performs localization using low-dimensional data, it is difficult to estimate even if the value deviates slightly from the model. In addition, LSTM has the advantage of being able to solve long-term dependence problem of traditional RNN, and it is possible to model it by non-linear mapping through analyzing the current situation without modeling data characteristics separately. Therefore, we propose RO SLAM technology using deep learning based

SLAM which applies the advantages of LSTM and deep learning to solve the disadvantages of RO SLAM.

D. ATTENTION

Attention is powerful module nowadays and mostly improves performance of neural network. Originally neural networks treats information equally. But, using attention layer, neural networks can be ATTENDED what it should be examined closely. At the first time, attention is utilized at natural language processing area for improving translation performance [26]. But nowadays, attention layer is employed in many areas to improve the performance of the networks. For example, Jaderbeg *et al.* [27] introduced the attention layer to let the neural networks attend to spatial information. In addition, attention is even utilized to pose estimation and optimization [28], detection [29], and video captioning [30]

III. GUIDELINES FOR GRAPHICS PREPARATION AND SUBMISSION

A. TYPES OF GRAPHICS

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2) Line Art figures

Figures that are composed of only black lines and shapes. These figures should have no shades or half-tones of gray, only black and white.

3) Author photos

Head and shoulders shots of authors that appear at the end of our papers.

4) Tables

Data charts which are typically black and white, but sometimes include color.

IV. RO NET

1) LSTM

LSTM is a type of Recurrent Neural Networks(RNNs) that has loops so that infer output based on not only the input data, but also the internal state formed by previous information. In other words, while the RNN deals with sequential data, the network has remembered the previous state generated by past inputs and might be able to output the present time step via internal state and input, which is very similar to filtering algorithms.

However, RNNs often have a *vanishing gradient problem*, i.e., RNNs fail to propagate the previous matter into present tasks as time step gap grows by. In other words,

TABLE 1. Units for Magnetic Properties

Symbol	Quantity	Conversion from Gaussian and CGS EMU to SI ^a
Φ	magnetic flux	$1 \text{ Mx} \rightarrow 10^{-8} \text{ Wb} = 10^{-8} \text{ V}\cdot\text{s}$
B	magnetic flux density, magnetic induction	$1 \text{ G} \rightarrow 10^{-4} \text{ T} = 10^{-4} \text{ Wb/m}^2$
H	magnetic field strength	$1 \text{ Oe} \rightarrow 10^3/(4\pi) \text{ A/m}$
m	magnetic moment	$1 \text{ erg/G} = 1 \text{ emu}$ $\rightarrow 10^{-3} \text{ A}\cdot\text{m}^2 = 10^{-3} \text{ J/T}$
M	magnetization	$1 \text{ erg}/(\text{G}\cdot\text{cm}^3) = 1 \text{ emu/cm}^3$ $\rightarrow 10^3 \text{ A/m}$
$4\pi M$	magnetization	$1 \text{ G} \rightarrow 10^3/(4\pi) \text{ A/m}$
σ	specific magnetization	$1 \text{ erg}/(\text{G}\cdot\text{g}) = 1 \text{ emu/g} \rightarrow 1 \text{ A}\cdot\text{m}^2/\text{kg}$
j	magnetic dipole moment	$1 \text{ erg/G} = 1 \text{ emu}$ $\rightarrow 4\pi \times 10^{-10} \text{ Wb}\cdot\text{m}$
J	magnetic polarization	$1 \text{ erg}/(\text{G}\cdot\text{cm}^3) = 1 \text{ emu/cm}^3$ $\rightarrow 4\pi \times 10^{-4} \text{ T}$
χ, κ	susceptibility	$1 \rightarrow 4\pi$
$\chi\rho$	mass susceptibility	$1 \text{ cm}^3/\text{g} \rightarrow 4\pi \times 10^{-3} \text{ m}^3/\text{kg}$
μ	permeability	$1 \rightarrow 4\pi \times 10^{-7} \text{ H/m}$ $= 4\pi \times 10^{-7} \text{ Wb}/(\text{A}\cdot\text{m})$
μ_r	relative permeability	$\mu \rightarrow \mu_r$
w, W	energy density	$1 \text{ erg/cm}^3 \rightarrow 10^{-1} \text{ J/m}^3$
N, D	demagnetizing factor	$1 \rightarrow 1/(4\pi)$

Vertical lines are optional in tables. Statements that serve as captions for the entire table do not need footnote letters.

^aGaussian units are the same as cg emu for magnetostatics; Mx = maxwell, G = gauss, Oe = oersted; Wb = weber, V = volt, s = second, T = tesla, m = meter, A = ampere, J = joule, kg = kilogram, H = henry.

RNNs are not able to learn to store appropriate internal states and operate on long-term trends. That is the reason why the Long Short-Term Memory (LSTM) architecture was introduced to solve this long-term dependency problem and make the networks possible to learn longer-term contextual understandings [31]. By virtue of the LSTM architecture that has memory gates and units that enable learning of long-term dependencies [32], LSTM are widely used in most of the deep learning research areas and numerous variations of LSTM architectures have been studied.

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