Neural Network-Based State Estimation of HIMR RFID System

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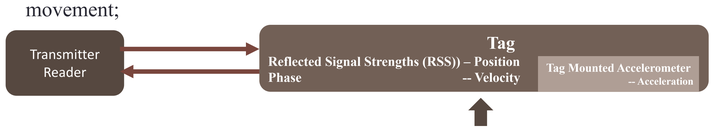
INTRODUCTION

- Fine-scale RFID motion capture and localization systems are potential candidates for emerging applications such as robotic wayfaring, virtual reality, remote motion capture, and tracking;
- Hybrid schemes have the highest accuracy (5-400 cm) and largest range (hundreds of meters) by combining a variety of sources;
- We proposed a feed forward neural network estimator with input in time window to get rid of recurrent units, pre-known control vector, and the dynamic model. The designed estimator is added to measurement position velocity and acceleration states based on RFID-based states algorithm..

RFID L&T SYSTEM

- Tag that is mounted with an accelerometer, moves along with the positioner arm;
- Reader receives compacted "(RSS + phase) $_{\text{from tag}}$ + (acceleration)$_{\text{from accelerometer}}$" data to obtain corresponding position, velocity and acceleration state data of the movement;



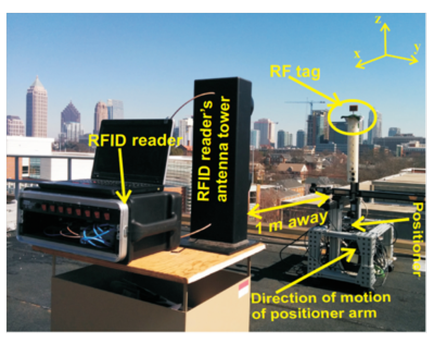


Fig.1 Physical setup of the HIMR RFID L&T test system setup, which is moved along a 1-D track with pre-programmed coordinates

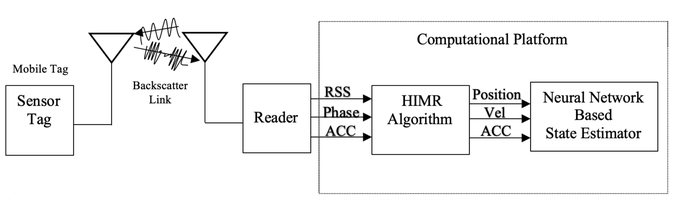


Fig. 2 An overview of how data is processed HIMR RFID system with one tag, one reader and a Kalman filter to enable precise real-time 1D motion capture.

NEURAL NETWORK ESTIMATOR

- Input states in time window to a feedforward architecture makes the temporal domain spatial, making it capable of memorizing previous states as recurrent units.
- In a recurrent neural network, a sequence of vectors is processed by applying a recurrence formula onto states at this time step and previous states in memory. At timestep t, the state of the unit is

$$h_t = f_W(h_{t-1}, x_t) = tanh(W_{hh}h_{t-1} + W_{xh}x_t)$$
$$y_t = W_{hy}h_t$$

- h_t is the new state, h_{t-1} is the previous state, x_t is the input vector at time step t, f_W is a function with parameters W, y_k is the output of recurrent neural network
- Constrain the length of recurrence to n (which is the batch size of input):

$$h_t = f_W(h_{t-1}, x_t) = f_W(f_{W'}(h_{t-2}, x_{t-1}), x_t)$$
$$= f_W(f_{W'}(\dots f_{W'\dots'}(f_{W'\dots'}(h_{t-(n+2)}, x_{t-(n+1)}), x_{t-n}) \dots, x_{t-1}), x_t)$$
$$y_t = W_{hy}h_t$$

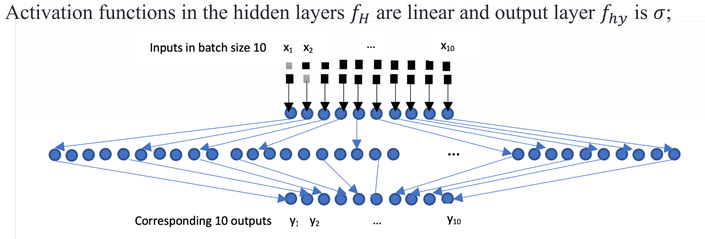
- The relationship between n inputs x_i, $i \in (0, t-n+1)$ and output y_k of recurrent neural network can be approximated as:

$$h_j = f_H\left(\sum_{i=1}^{n} w_{ij}^h x_i + b_j^h\right)$$
$$y_k = f_{hy}\left(\sum_{j=1}^{m} w_{ij}^o h_j + b_j^o\right)$$

- Which are the formulas of a general feedforward neural network. $h_j$are the outputs of neurons in the hidden layer and y_k are the output of neurons in the output layer. f_H is the identity function, f_{hy} is σ function.
- In this way, weights from inputs x_t, x_{t-1},…, x_{t-n+1} to output y_t can be learned from a feedforward neural network.

ESTIMATOR STRUCTURE

- A 3-layer sequential neural network model composed of 10, 80, and 10 neurons;
- The time window of size 10, the processor will wait until 10 states arrive and then process continuously on the new state and 9 previous states all together;
- Activation functions in the hidden layers f_H are linear and output layer f_{hy} is σ;



- 80% of the position states are used for training and 20% are for testing;
- The measurement position data are input at a batch size of 10. The model is trained with 200 epochs;
- Mean square error is minimized by adam optimizer during the training;

RESULTS

- Estimated routes is of much lower noise level compared to measurement
- RMS error before estimation is 31mm after estimation is 14m for test states, which is a factor of 2 enhancement

Measurement RMS Error	Estimation RMS Error on Test Position
31 mm	14 mm

ESTIMATION RESULTS

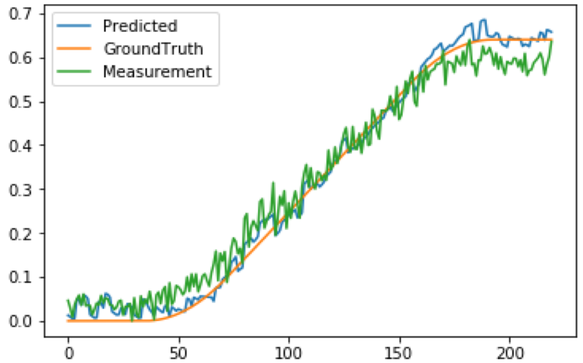


Fig.3 Estimation Results for HIMR RFID Position Measurement

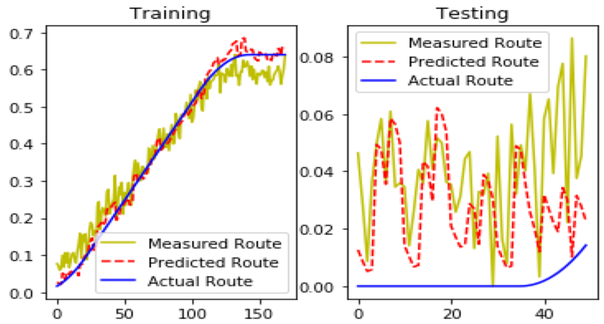


Fig.4 Estimation Results for Training and Testing Position Data

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