Demo Abstract: Collision Prediction from Pairwise Ranging

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ABSTRACT

The ability to predict, and thus react to, oncoming collisions among a set of mobile agents is a fundamental requirement for safe autonomous movement, both human and robotic. This demonstration tests a pairwise method in which two agents collect repeated range measurements and predict if they will collide. Compared to methods which use GPS or TDOA to track each agent and then predict collisions, this method does not rely on infrastructure or a fixed coordinate system. However, the accurate prediction of future pairwise range, and thus collision prediction, is highly sensitive to noise and changes in velocity. This prototype can be used to provide intuition for the method's strengths and weaknesses.

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1 INTRODUCTION

As the prevalence of autonomous drones increases, so does the challenge of making sure they do not collide. Drones have crashed into other drones or other aircraft, and a drone's presence sometimes prevents others (commercial aircraft, helicopters) from flying for fear of collision. We cannot expect air traffic controllers to manage all aerial vehicles. Commercial aircraft transmit and receive ADS-B signals, but these rely on the correctness of GNSS signals which can be jammed or spoofed by individuals or governments [2]. Vision or lidar sensing approaches will be useful for nearby or large targets.

In this demo, we investigate a complementary sensing method for collision prediction and avoidance using ultra-wideband (UWB) range measurements between autonomous devices, each with their own UWB transceiver. Such a system requires no known-location deployed devices, and UWB transceivers are low cost, physically small, and consume little energy. As we demonstrate, collision prediction from ranging is a distributed and real-time system.

The objective in collision prediction is to detect whether or not the future trajectories of two agents will result in their impending collision. Such task involves determining the relative distance between the agents as a function of time and hence depends entirely on the relative kinematics of the pair. For nodes with constant velocities, One does not need knowledge of absolute kinematics. For this demonstration, we assume the motion of each agent can be approximated with constant velocity for a short time interval.

Here, we demonstrate collision prediction between a single pair. We assume that node A and B, initially located at positions $\mathbf{x}_A$ and $\mathbf{x}_B$, move at constant velocities $\mathbf{v}_A$ and $\mathbf{v}_B$, respectively, as shown in Figure 1a. Relevant to collision prediction is the relative position $\mathbf{x} = \mathbf{x}_B - \mathbf{x}_A$ and relative velocity $\mathbf{v} = \mathbf{v}_B - \mathbf{v}_A$.

To have an impending collision, the predicted trajectory must bring the centers of the agents too close to each other *and* within a short period of time. We are not using ranging to predict long-term problems in the planned path, and at some passing distance the predicted motion is safe. Thus two critical *collision prediction (CP)* parameters are:

- d_m: The minimum passing distance between two nodes, and
- t_m: The time at which the relative distance reaches its minimum.

For initial relative position $\mathbf{x}$ and relative velocity $\mathbf{v}$, these are calculated as:

$$\begin{aligned} t_m &= -\frac{\mathbf{x} \cdot \mathbf{v}}{v^2}, \quad \text{where } v = \|\mathbf{v}\|, \\ d_m &= \frac{1}{v}\sqrt{\|\mathbf{x}\|^2\|\mathbf{v}\|^2 - (\mathbf{x} \cdot \mathbf{v})^2} \end{aligned} \tag{1}$$

We model the danger zone as a sphere with radius r; if $d_m < 2r$ the future path is hazardous. In this definition the collision occurs when the passing equals $2r$, which is before t_m whenever $d_m < r$. This time of collision t_c is:

$$t_c = t_m - \frac{1}{v}\sqrt{4r^2 - d_m^2} \tag{2}$$

The values of CP parameters estimated for a pair of mobile agents can used to determine if there is future collision. The accuracy of a collision prediction method can be evaluated in terms of on its performance in accurately estimating of these parameters.

In this demo, we apply quadratic regression on squared distance measurements to determine CP parameters and future distance between two node moving linearly relative to each other.

2 EXISTING APPROACHES

Based on literature, the most intuitive approach to predict collision using UWB ranging involves first tracking of the positions of individual agents and then determining the likelihood of intersection of their trajectories. UWB-based localization and tracking usually require nodes with fixed known location [5], which entails the need for setting up infrastructure and initial calibration. Collision prediction is fundamentally different from localization in that it does not require knowledge of absolute location as it depends on only relative kinematics such as relative position and relative velocity. Several relative localization methods based on

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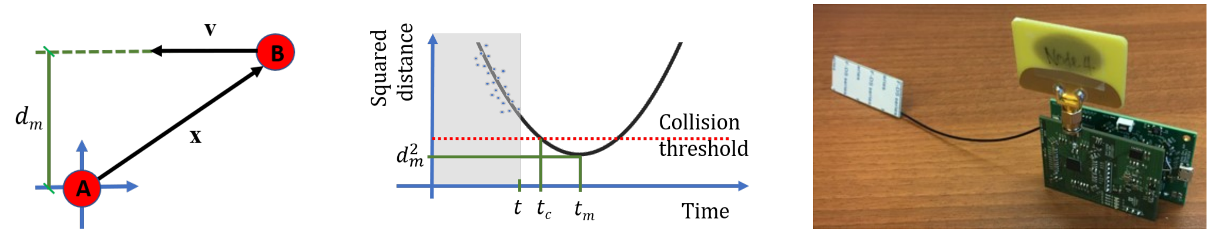

(a) (b) (c)

Figure 1

ranging measurements have been proposed. For example, classical approaches use Multi-Dimensional Scaling(MDS) to generate a relative map from pairwise distance measurements. However, such relative position estimates cannot be directly in collision prediction or tracking because successive position estimates can be translated and/or rotated. Rajan et al. proposed a modified MDS in which relative velocity is estimated from second order derivative of squared distance measurements [4]. Yet, this method results in less accurate velocity estimates for noisy measurements and hence it is not suitable for collision prediction. The work by Coppola et al. on collision avoidance fuses various sensor data including Bluetooth signal strength [1]. Nonetheless, due to its dependence on Bluetooth signal strength, their system heavily suffers from interference. In this demo, we show the use of pairwise UWB ranging for accurate collision prediction.

3 SYSTEM IMPLEMENTATION

We implement UWB ranging using commercial IR-UWB transceivers. As shown in Figure 1c, each node is equipped with an Arm Cortex-M4 processor connected to an IR-UWB transceiver, a narrowband transceiver, and a shared Voltage Controlled Temperature Compensated Crystal Oscillator (VCTCXO). We use on Decawave's DW1000 IR-UWB radio which supports IEEE 802.15.4a and time-of-arrival (TOA) estimates can be computed from message timestamps [6]. For clock synchronization, we adopt radio frequency synchronization (RFS) method proposed in [3] in which one node periodically broadcasts a continuous-wave (CW) signal using TI's CC1200 narrowband transceiver and the other node computes carrier frequency offset and adjust its VCTCXO frequency.

The ranging starts with a node transmitting unmodulated CW signal over a narrowband channel for clock synchronization. Up on receiving the narrowband signal, the other node applies RFS to synchronize its clock. Next, the nodes exchange timestamp data via UWB. Each node keeps track of its transmit and receive timestamps to compute time of flight. Clock synchronization is performed periodically after every 100 cycles.

Our collision prediction method uses only pairwise range measurements. Assuming nodes with linear motion, the squared distance between a pair d^2 is a quadratic function of time as shown. and can be expressed in terms of CP parameters as

$$d^2(t) = d_m^2 + v^2 (t_m - t)^2 = a_0 + a_1 t + a_2 t^2 \quad (3)$$

We apply quadratic regression on a sequence of squared pairwise range measurements in real time to determine CP parameters as follows

$$\begin{aligned} t_m &= -\frac{a_1}{2a_2} \\ d_m &= \sqrt{a_0 - \frac{a_1^2}{4a_2}} \\ v &= \sqrt{a_2} \end{aligned} \quad (4)$$

Then, future collision is detected when the estimated CP parameters $\hat{d}_m$ and $\hat{t}_m$ are below selected threshold values.

4 DEMONSTRATION

In this demonstration, we show collision prediction between two moving objects consisting UWB sensors. Each node comes in a round package of diameter 0.3m. When one or both nodes move linearly, the possibility of intersection of their trajectories at the same time is determined in real time using pairwise UWB ranging. This demonstration involves lighting to indicate an impending collision a second before the two moving containers touch each other. The demo is conducted in a space with $3m \times 3m$ area.

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