Motion Safety with People: an Open Problem

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***Abstract*— In this presentation, we explore and question the concept of motion safety, *i.e.* the ability to avoid collision, for robots sharing their workspace with people. We establish that *absolute motion safety*, in the sense that no collision between the robot and the people will ever take place, is impossible to guarantee (hence the open nature of the motion safety problem). We then discuss the choices that are available: mere *risk minimization* or what we call *weaker motion safety*, *i.e.* types of motion safety that are weaker than absolute motion safety but that can actually be guaranteed. In all cases, we argue that if robots are ever to be deployed among people, it is important to characterize the level of motion safety that can be achieved and to specify the conditions under which it can be guaranteed.**

INTRODUCTION

Roboticists have long been aware of the motion safety issue and there is a rich literature on this topic starting with the pioneering work of [1] for a mobile robot. A huge number of approaches have since been proposed in order to develop "safe" robots. Said approaches were usually validated through simulation, laboratory or real world experiments. It is only recently that motion safety has been investigated in a more theoretical manner [2]. Demonstrating that a robotic system is working properly on a limited set of experiments is not enough. If robots are ever to be deployed among people on a large scale, there is a need to characterize the level of motion safety that can be achieved and to specify the conditions under which it can be guaranteed. Robotic collisions happens for a number of reasons:

- Hardware failures, *e.g.* brake failure.
- Software bugs, *e.g.* truncation error.
- Perceptual errors[1], *e.g.* false negative.
- Reasoning errors, *i.e.* a wrong decision is made.

We focus herein on reasoning errors (at both the deliberative and reactive levels) and rely upon the concept of Inevitable Collision States[2] [3] to better understand motion safety.

DYNAMIC ENVIRONMENTS

Environments with people are *dynamic* (yes, people move). Building upon [4], we first highlight key requirements for motion safety in dynamic environments; they are fairly intuitive and straightforward to express in two sentences:

> In a dynamic environment, one has a *limited time* to make a motion decision. One has to *globally reason about the future* evolution of the environment and do so with an *appropriate time horizon*.

Accordingly, provided that (1) the decision time constraint can be met, and (2) a complete model of the future is available up to the appropriate time horizon, then it is possible to design navigation strategies for which *absolute motion safety*, *i.e.* no collision will ever takes place, can be formally guaranteed (check the results reported in [5]). As encouraging as these results are, we see next that things are not so rosy in environments with people.

UNCERTAIN ENVIRONMENTS

Environments with people are *uncertain* (how will people move can be difficult to predict). In other words, complete information about the environment and its future evolution is not available. To address this issue, two solutions have emerged in order to build the space-time model of the future which is required for motion safety:

- *Conservative modeling*: it considers all possible future motions of moving objects. Each object is assigned its *reachable set*, *i.e.* the set of positions it can potentially occupy in the future, to represent its future motion.
- *Probabilistic modeling*: the evolution of a moving object is captured within a *stochastic transition function* and the tools used to predict its future behaviour are diverse, *e.g.* Kalman Filters. The position of an object at any given time is then described by a *probability density function*.

Conservative models solve the problem of the discrepancy between the predicted future and the actual future. In theory, it becomes then possible to develop navigation strategies whose motion safety is guaranteed. In practice however, the monotonous growth of the region reachable by an object is such that, eventually, the whole environment becomes potentially occupied by the object. As a direct consequence of that, every state for the robot becomes an ICS since every possible trajectory eventually drives the robot to a collision state. Accordingly, any navigation strategy with proven collision-avoidance guarantee would fail to find a solution.

Probabilistic models were introduced to address this issue. However, introducing probabilities clearly entails a major paradigm shift. So far, everything was black and white so to speak: collision *vs* no collision. When entering the realm of

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[1] Errors related to the robot's perception system that yield an incorrect understanding of its situation.

[2] State such that, no matter what the robot's future trajectory is, a collision eventually occurs.

probabilities, everything turns grey and collision probabilities are in order. As sound as the probabilistic framework is, it cannot provide *strict motion safety guarantee*, strict in the sense that they can be established formally. Minimizing the collision risk is the only thing that can be done.

RISK MINIMIZATION *vs* WEAKER MOTION SAFETY

At this point, it appears that absolute motion safety is impossible to guarantee in an environment with people. The only way to attain absolute motion safety is to consider a conservative model of the future but we have seen how ineffective it is. Probabilistic models are ideal to handle the uncertainty that prevails in an environment with people but they do not allow strict motion safety guarantees, only *risk minimization*. In an effort to improve the situation and to provide strict motion safety guarantees, we would like to advocate an alternative approach that can be summarized by the following motto:

Better guarantee less than guarantee nothing.

The idea is to settle for levels of motion safety that are weaker than absolute motion safety but that can be guaranteed. We describe one example of such a *weaker motion safety* that has been explored in [6]. It guarantees that, if a collision must take place, the robot will be at rest. This motion safety level has been dubbed *passive motion safety*. As limited as it may appear, passive motion safety is interesting for two reasons: (1) it allows to provide at least one form of motion safety guarantee, and (2) if every moving object in the environment enforces it then no collision will take place at all (and it seems reasonable to assume that people are also striving to avoid collisions).

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