Contextual processing for pedestrian tracking in GPS-denied environments

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ABSTRACT

This paper introduces the contextual processing (CTXP), a novel and powerful concept for pedestrian tracking in GPS-denied environments. Its major advantages are: no need of external, ad-hoc infrastructures, no need of floorplans, low cost/weight/size, no need of calibrations or fingerprinting measurement campaigns, accuracy independent of the walked distance. In addition, CTXP processing is light enough to be hosted in a pocket-size commercial smartphone/tablet. CTXP has been extensively tested by Italian and International Agencies and industries in a widespread ensemble of scenarios (e.g. battleships, vessels, large industrial plants, malls) with experiments durations up to 3 hours and walked distance up to 6 km, always providing end-to-end results compliant with the target requirements.

Categories and Subject Descriptors

J.4 [**Computer Applications**]: Social and Behavioral Sciences – *economics, sociology.*

J.7 [**Computer Applications**]: Computers in Other Systems – *command and control, industrial control, military.*

General Terms

Algorithms, Performance, Reliability, Experimentation, Theory, Verification.

Keywords

Processing, IMU, Pedestrian tracking, MEMS, PDR, Experiment.

1. INTRODUCTION

Scrutinizing the current SoA, the better performing solutions are based on the exploitation of two major sources of information: intrinsic (human-centric) and extrinsic (infrastructure-centric) information. The former is relevant to the operator himself and is basically limited to the information coming from body-mounted sensors (e.g. IMUs, barometer, compass, laser scanners); the latter is the information: a) extracted from external sources (e.g. radio beacons, UWB devices, 3G/4G base stations, WiFi hotspots) that can be ad-hoc deployed or can be just sources of opportunity or b) a priori information (e.g. flooplans, maps).

The major advantage of the intrinsic information is that no infrastructure is needed (expensive to deploy and maintain), but this comes at the cost of poor performance, as the available body-mounted sensor technology is not yet mature enough to insure an acceptable accuracy in the long term (hours). The solely use of extrinsic information has weak points as well, as the infrastructure cost, deployment time and maintenance can hardly meet the CAPEX/OPEX budget and the set-up time constraints.

The better performing systems employ intrinsic information augmented by extrinsic information (e.g. joint use of IMU body sensors and UWB TX); on one hand the accuracy boost can be significant, on the other hand the drawbacks and limitations due to the CAPEX/OPEX and deployment time of the infrastructure(s) can easily jeopardize the real adoption of such systems.

The authors, starting from the results of the RESCUE and EXPLORERS projects (co-funded by Italian research initiatives), beside the intrinsic and extrinsic domains, introduce a novel information domain: the contextual domain that has demonstrated (more than one hundred of on-field experiments) to lead to unprecedented performances in terms of accuracy, cost, weight.

2. THE CONTEXTUAL PROCESSING

2.1 The Contextual Domain

The contextual domain is the information coming from the behavioral features extracted from the walked path. For instance, when a pedestrian, after some time, crosses again a point previously crossed, this generates a contextual information. Indeed, a typical PDR processing, because of mismatches and drifts, would estimate these points (actually matching in the ground truth) as separate points in a 3D space. The same happens, by analyzing the spatial pattern of specific elements of the walked path; for instance, when some stairs are waked upward and then, after some time, are walked downward, the two typical "stairs-shaped" patterns are estimated, because of the drifts and scale factors, as dislocated in space by a PDR processing.

In other words, the contextual information is always related to points or elements of the path crossed again after some time. Each time a contextual point is detected, the DUNE proprietary Contextual processing (CTXP) software estimates the (many) mismatches and drift factors, providing a backward compensation of the estimated path and, at the same time, a superior compensation of the forthcoming track, still to be walked.

On a statistical base, the presence of contextual points has been verified in practically all the scenarios and situations analyzed so far. In some scenarios the presence of contextual points is very high (e.g. ships and vessels); in other scenarios is pretty good (e.g. malls). Only in some very specific cases are hardly to happen (e.g. inspector visiting a nuclear plant), but in this special cases the cooperating inspector purposely crosses again a few previously visited points, so to generate the contextual information.

2.2 The DUNE System

The whole system is made of simple elements: a foot-mounted MEMS-based IMU sensor unit (20 g, 30x30x25 mm) also hosting the PDR processing; the uncompensated, drift-affected, estimated path is transmitted via BT link to a commercial smartphone/tablet, where the DUNE proprietary Android App provides a first drift compensation based on barometer, compass and GPS data (if available and if reliable) as well as the logging of the detected context points (that can be automatic or manual, depending on the application). The uncompensated track and detected contextual points are then processed by the CTXP software.

3. EXPERIMENTAL RESULTS

The CTXP has undergone so far to more than 100 experiments and in all of them (purposely) no information coming from the GPS or the compass has been ever employed. The scenarios range from malls, large urban areas, industrial plants to battleships and vessels (in harbor and in navigation) and underground caves. The experiments have been carried out by different walkers, with or without still phases as long as 1 hour (e.g. emulating a meeting or a dinner) and with no need of calibrations or mandatory starting path shapes, with durations up to 3 hours and walked distance up to 6 km.

Figure 1 represents the uncorrected, purely inertial path estimated by a 15-states Kalman filter PDR algorithm (no GPS or compass information is employed) for a mixed indoor-outdoor experiment. Duration: 1 h, 49 m; walked distance 5.300 m; 5 context points detected. The significant residual drift makes the estimated path useless after just a few hundred meters.

Figure 2 represents the same path of Figure 1, but with the adoption of the CTXP: the result is good over the whole path, leading to start-end error of 0.5 m (after 5.3 km of walked distance). Similar results have been obtained from all the experiments performed so far, from which it has been possible to estimate that the achievable 3D accuracy is largely independent of the walked distance, hardly exceeding 3-4 meters in the horizontal plane, whereas in the vertical plane 0.2 m is a typical value.

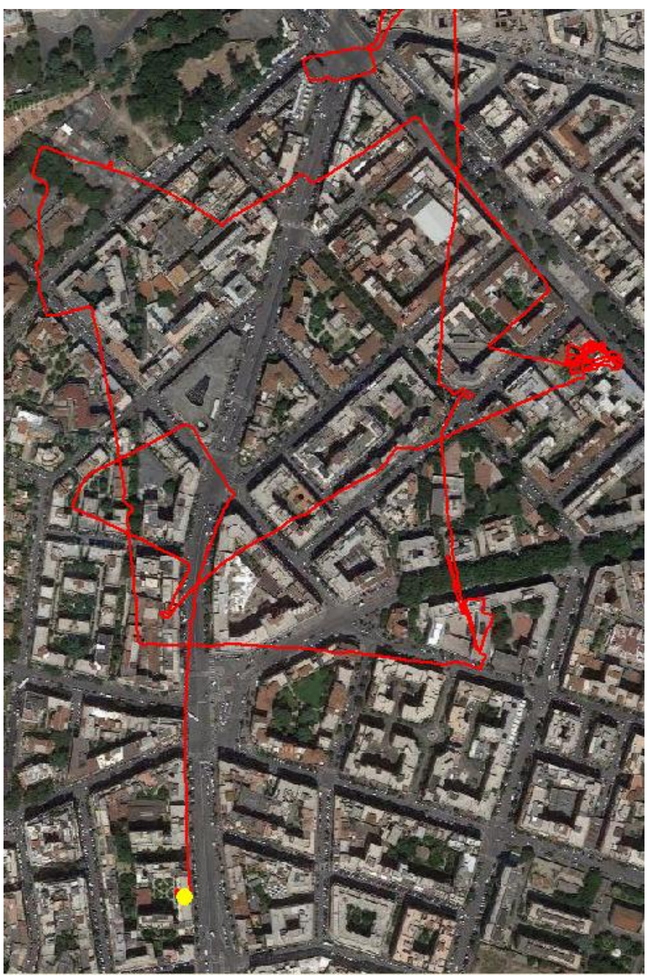

Figure 1. Purely inertial path estimated with a SoA PDR algorithm.

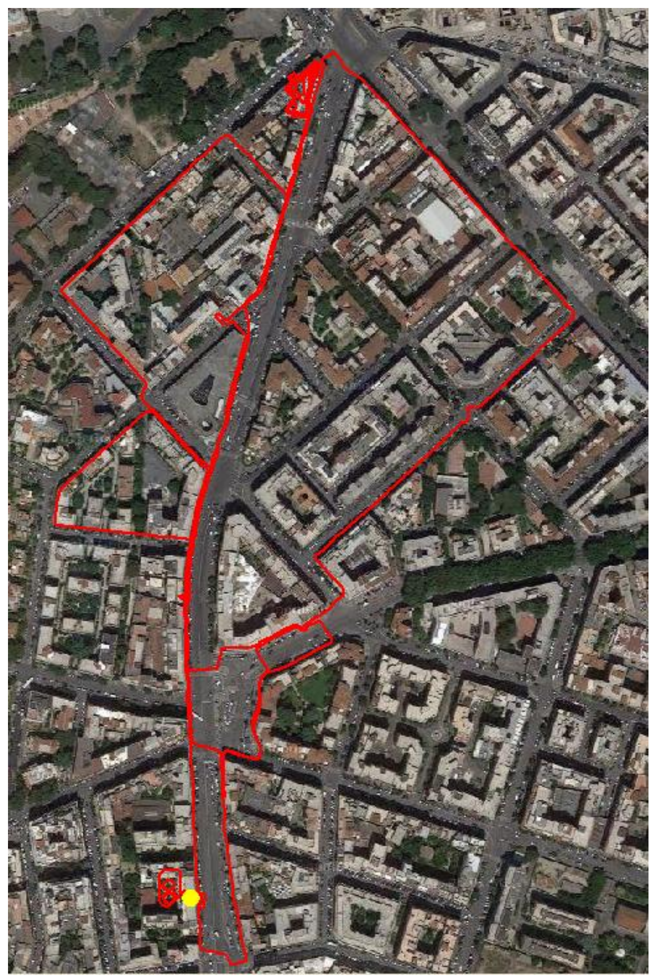

Figure 2. Same path as Fig.1, but processed with the DUNE Contextual Processing.