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Semi-automatic template matching based extraction of hyperbolic signatures in ground-penetrating radar images

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In civil engineering applications, ground-penetrating radar (GPR) is one of the main non destructive technique based on the refraction and reflection of electromagnetic waves to probe the underground and particularly detect damages (cracks, delaminations, texture changes…) and buried objects (utilities, rebars…). An UWB ground-coupled radar operating in the frequency band [0.46;4] GHz and made of bowtie slot antennas has been used because, comparing to a air-launched radar, it increases energy transfer of electromagnetic radiation in the sub-surface and penetration depth.
This paper proposes an original adaptation of the generic template matching algorithm to GPR images to recognize, localize and characterize with parameters a specific pattern associated with a hyperbola signature in the two main polarizations. The processing of a radargram (Bscan) is based on four main steps. The first step consists in pre-processing and scaling. The second step uses template matching to isolate and localize individual hyperbola signatures in an environment containing unwanted reflections, noise and overlapping signatures. The algorithm supposes to generate and collect a set of reference hyperbola templates made of a small reflection pattern in the vicinity of the apex in order to further analyze multiple time signals of embedded targets in an image. The standard Euclidian distance between the template shifted and a local zone in the radargram allows to obtain a map of distances. A user-defined threshold allows to select a reduced number of zones having a high similarity measure. In a third step, each zone is analyzed to detect minimum or maximum discrete amplitudes belonging to the first arrival times of a hyperbola signature. In the fourth step, the extracted discrete data (i,j) are fitted by a parametric hyperbola modeling based on the straight ray path hypothesis and using a constraint least square criterion associated with parameter ranges, that are the position, the depth, the velocity and if possible the target lateral dimension.
All the algorithm has been implemented and evaluated on numerical radargrams (FDTD simulations), then on experimental radargrams using two polarization configurations. Buried pipe targets have been mainly characterized. The algorithm has shown that distinct templates have to be associated with both polarizations. Depending of the level of details required, several templates may be successively used to identify progressively the dielectric nature of a buried target among several in a radargram. Considering measurements in a controlled environment, this work has shown that synthetic templates can be used to analyze radargrams provided that the templates have the same time step and amplitude range adjusted if necessary by interpolation. As a whole, we have remarked that the recognition algorithm appears robust. Further studies will be focused on making measurements of different buried targets representing utilities and cracks on the surface of our novel test site that will be built in the project Sense-City [1].

[1] http://www.sense-city.univ-paris-est.fr/index.php