자갈도상 철도지반에서의 열화층 식별을 위한 GPR 시뮬레이션 프로그램 개발

Development of a GPR simulation program to identify fouled layer in ballast railway ground

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Introduction

- This study involves a developed Graphic User Interface (named as KIT-GPR) Program based on Finite Difference Time Domain (FDTD) of Ground Penetrating Radar (GPR) to detect the condition of railway ballast.
- The program aims to provide accurate and reliable information about the ballast conditions, which is essential for maintaining the safety and efficiency of railway tracks.
- Results of the KIT-GPR program were compared to gprMax software and measurement results of the ballast condition, showing compatibility and high accuracy.

Methodology

- The fundamental theory of developed program is considered to the Maxwell's curl equation in the frequency domain, which presented as

$$\nabla \times \mathrm{E} = -i\omega\mu\mathrm{H} \quad (1)$$

$$\nabla \times \mathrm{H} = \sigma\mathrm{E} + i\omega\varepsilon\mathrm{E} \quad (2)$$

Where $i = \sqrt{-1}$, ω is the angular frequency, ε, μ, and σ are the dielectric permittivity, magnetic permeability, and electrical conductivity, respectively, and E and H are the electric and magnetic field vectors.

- The Governing Equations (1) and (2) are solved using the Finite Difference Time Domain, as explained in detail with MATLAB open-source code by Irving et al. (2006).

Development of a GPR Simulation Program

- The C# language was used to develop the KIT-GPR program. There are three modules: geometry definition, analysis, and preprocessing. The program automatically computes the parameters necessary for FDTD method, such as time step and element size, and provide suggestions to the end-user.

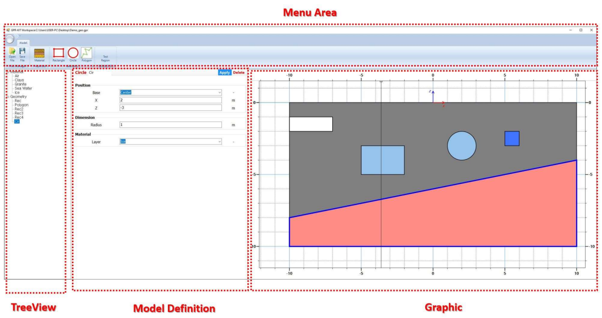
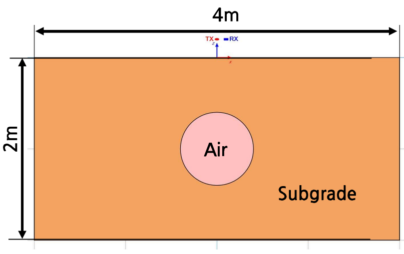


Fig 1. Developed Graphic User Interface of KIT-GPR Program

KIT-GPR Program Validation

- The cavity under ground model is utilized to validate the KIT-GPR program, which are then compared to those modelled by gprMax software. The geometry and material parameters are shown in Figure 2. In addition, Ricker waveform is adapted for antenna.



Material	Parameter		
	ε	σ (mS/m)	μ
Air	1	0	1
Subgrade	3	10	1

Fig 2. Geometry and Input parameters of Validation model

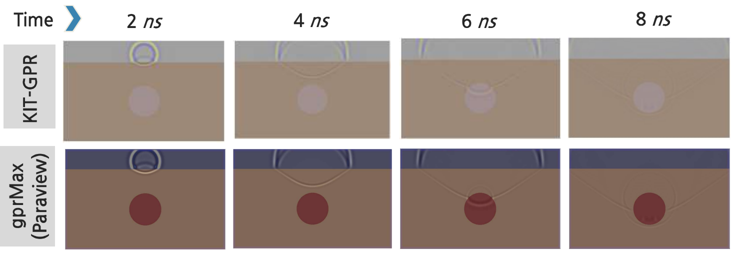


Fig 3. Comparison of snapshots showing the amplitude of E_y wave field (x = 2m)

- As shown in Figure 3, Ey wave snapshots from KIT-GPR and gprMax program are similarities. However, KIT-GPR program has an advantage over gprMax as it has integrated post-processing solutions. This means that KIT-GPR program does not require third-party software like Paraview to show results, unlike gprMax. In addition, Figure 4 shows the B-scan obtained from KIT-GPR and gprMax programs. The reflected wave indicates the cavity position and direct wave of antenna appear similar.

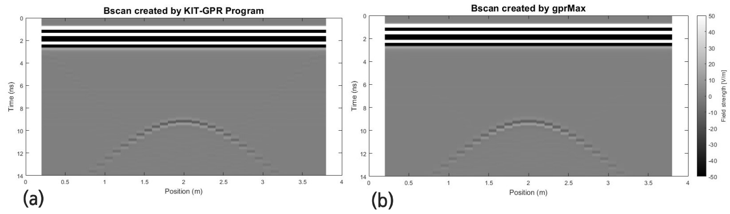


Fig 4. Comparison of B-scan: (a) KIT-GPR Program; (b) gprMax Program

Railway Ballast Condition Assessment by KIT-GPR

Under repeated loading, railway ballast particles are often abraded, causing fine particles to fill the gaps between larger particles. Consequently, two subclasses of ballast are created: Clean Ballast and Fouled Ballast (Fig 5. a). In order to determine the working thickness of the ballast layer using GPR, a scale model was constructed in a laboratory. Measured data was collected using a GSSI 400 MHz GPR antenna (Fig 5. b). Afterward, a similar model was created on KIT-GPR software for further analysis (Fig 5. c)

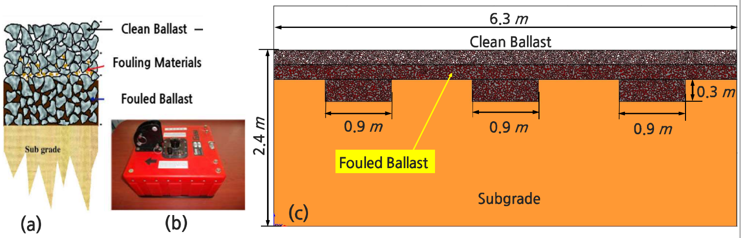


Fig 5. Railway Ballast Condition Modelling: (a) Ballast Condition; (b) GSSI 400MHz Antenna (b) Simulation Model in KIT-GPR Program

In simulation model, the parameters for subgrade and air are similar to those in the validation model. The particle parameters of ε, σ, and μ are set to 6, 5e-3, and 1, respectively. To simulate antenna waves, Gaussian waveform with a central frequency of 392.4 MHz are used. The B-scan results are normalized and compared to the measured data from the GSSI 400 MHz antenna. In Figure 6, the B-scan simulated by KIT-GPR can easily distinguish the working thickness of Clean Ballast and the structure of the Fouled Ballast layer. In addition, the results from the simulation model are also quite similar to the experimental B-scan measured by the GSSI 400 MHz antenna.

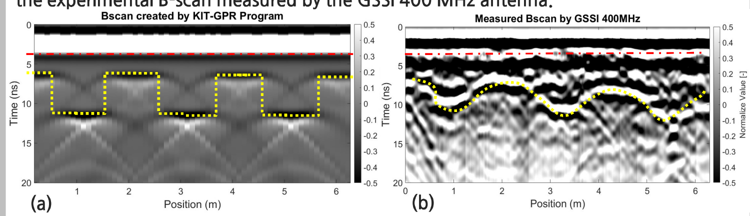


Fig 6. Comparison of B-scan: (a) KIT-GPR Program; (b) Measured Data by GSSI 400MHz

Conclusion

- This research contains a development of KIT-GPR simulation program with three modules: geometry definition, analysis, and postprocessing. The user interface is accessible and user-friendly. The results from KIT-GPR program were compared to those model by gprMax software, as well as experimental measurement results using the GSSI 400 MHz antenna. The results showed high accuracy and similarity. Therefore, KIT-GPR program is suitable for determining the working conditions of ballast layer in railway maintenance.

Acknowledgements

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Reference

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