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Analysis of the Information Relationship between Measurement Configurations and Control-Relevant Process Variables for Automatic Control of Jacked Pile Installation

Pogodaev A.K., Liu Ting, Sun Chuanjia

Lipetsk State Technical University

Lipetsk, Russian Federation

Digital monitoring systems can record jacking force, penetration depth, and pile-position deviation during jacked pile installation [1], while instrumented field and model studies extend the available information to pore-water pressure, soil stress, and separated resistance components [2,3]. Thus, construction information depends on the sensors, data fields, and interfaces employed. For automatic control, the relevant question is what information a given configuration provides and how it supports control-relevant process variables.

Measurement configuration and information-formation method play different roles: the former limits available data channels, whereas the latter describes how target variables are obtained by direct measurement, derivation, calibrated conversion, or model-based estimation. Because a complete equipment–pile–soil dynamic model is not established here, the selected quantities are treated as candidate process variables rather than a finalized state vector. To represent construction progress, penetration motion, actual equipment action, and pile–soil interaction, respectively, we select

$$z_c = [h \;\; v \;\; F_a \;\; R]^T \tag{1}$$

where h is the penetration depth, v is actual penetration velocity, F_a is the jacking force actually transmitted to the pile, and R is a low-order equivalent pile–soil resistance. F_a is distinct from the control command; R excludes equipment-side losses. Instrumented shaft, plug, annulus, and base resistance components provide physical information but are not individually identical to R [2,3].

Information paths differ by configuration: h may be measured directly; v may be measured or derived from $h(t)$. F_a may be measured or converted from calibrated

hydraulic signals. Information on R additionally requires a physical definition, specified force and model relations, and appropriate recoverability conditions. Table 1 summarizes these relations.

Table 1. Candidate process variables and information-formation conditions

Variable	**Information formation**	**Main conditions**
Depth h	Direct depth or displacement measurement	Datum, calibration, synchronization
Velocity v	Direct measurement or derivation from $h(t)$	Sampling, timestamps, differentiation and filtering
Jacking force F_a	Force measurement or calibrated hydraulic conversion	Pressure–force and transmission relation, calibration
Equivalent resistance R	Pile–soil response constraints; model-based estimation	Definition, force and model relation, parameters, recoverability

Measurement configuration and information-formation method are distinguishable but mutually constrained. With only depth measurement and reliable timestamps, h is obtained directly and v can be derived. Adding a calibrated force signal supports F_a but does not by itself determine R. Additional pile-strain or surrounding-soil measurements provide further pile–soil information, subject to sensor placement, variable definition, and model assumptions.

For control-side measurements representable under a given low-order description and measurement assumptions, the relation for configuration j may be written conceptually as

$$y_c^{(j)} = g_c^{(j)} \left(z_c; D_c^{(j)}, \theta_y\right) + v^{(j)} \tag{2}$$

where $y_c^{(j)}$ is the measurement vector, $g_c^{(j)}$ is the measurement mapping, $D_c^{(j)}$ is the sensor and data-interface configuration, θ_y denotes measurement and calibration parameters, and $v^{(j)}$ is measurement error. Equation (2) is conceptual only: research-oriented responses need not be uniquely determined by z_c. and derivation, filtering, calibration, or model-based estimation require separate processing relations.

When a process variable is defined as a state or augmented state in an explicit dynamic model, its recoverability can be examined by observability analysis for given inputs, parameters, and measurements; practical estimation also depends on sampling, noise, calibration, and model mismatch [4]. Direct measurability and indirect acquisition must therefore be assessed separately for the specific configuration and model conditions.

In conclusion, h, v, F_a , and R are selected as candidate control-relevant process variables for jacked pile penetration. Measurement configuration and information-formation method are two distinguishable but mutually constrained aspects: available data channels alone do not determine whether a target variable is directly measurable or can be acquired indirectly. Such judgments also depend on calibration, information processing, and model assumptions.

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