Assessment of urban tree condition using sonic tomography technology

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Abstract. Trees are an important biodiversity component in urban landscapes where their performances have to be monitored regularly in order to secure public safety as well as to avoid damages on humans and properties. Tree risk monitoring and assessment are conducted based on visual tree inspection as the principal method. However, in certain cases, the results from tree inspection still require supporting information generated from special equipment in order to clearly determine the internal condition prediction of assessed trees. We have investigated more than 300 trees of about 15 species located in several public areas in Jakarta. The objective of this study was to determine the internal condition of the main trunk of the tree main at 1.3 m height using PiCUS® sonic tomography. We categorized the status of the tree trunk condition based on the percentage of solid wood from the tomogram image. The results showed that about 80% of the main trunks of the tree were in sound condition, 12% were in moderate condition, and the rest was in worst condition. The final evaluation of the tree condition should have also considered the result of the visual condition.

1. Introduction
In urban areas, trees are generally considered as an important part and desirable for landscape development. Urban trees perform important functions in term of the environment, aesthetic and ecological by controlling microclimate, sequestering carbon, removing airborne pollutants, as well as giving high value in urban areas as part of the green infrastructure, the identity of the city, and part of the history [1]. The dangers associated with urban trees can be problematic in ensuring community and properties safety. In many cases, trees can be harmful to the target, even lethal, under the right conditions because the sign and symptom of tree defect are not identified properly. This is due to the monitoring and assessments of the status and health of the tree have not received feasible attention.

In tree risk monitoring and assessment, there are three purposes which should be given attention: (1) public safety, (2) protection of workers on job site, (3). promotion of tree longevity by predicting and preventing structural failure. For this reason, the targeted location of people, equipment, and other properties that were likely to congregate should be known. Tree risk assessment is developed from visual inspection as the principal method. Identification of the defects of the tree which includes abnormal growth is a way to mitigate the tree risk through Visual Tree Assessment (VTA) which was
developed by Mattheck and Breloer [2, 3]. Defective trees, or a part of it (the tree), that possess a high risk of its failure or fracture to cause injury or damage to people and property can be hazardous trees.

In arboriculture practice, the technology is used to detect and quantify the interior part of the tree for predicting the location of wood decay and other deterioration. Sonic tomography is a technique used to produce an image of the internal cross-sectional structure of a tree by recording differences in the speed of sound wave transmission. The information from the equipment with other factors relevant to the safety of the tree, i.e. visual tree assessment, could be used in order to make an accurate risk assessment.

The aim of this study was to assess trees in urban landscape in some commercial areas in Jakarta through determination internal condition of tree main trunk based on sonic tomography which also conducted the visual assessment.

2. Materials and methods

The study was carried out in 4 (four) public areas which were consisted of district business area, wildlife park areas, hotel and convention area, and the embassy area around Jakarta. The target trees were trees with trunk with diameter ≥ 30 cm which have been listed cultivatated around the targeted areas [4,5,6].

Tree inspection was carried out to visually evaluate the common defects condition of the tree which was in the crown, branches, trunk, and roots described based on decay indicators. Most of the defects can be linked to wounding which occurred in the past, pest infestations, and destroyed or wood decay. Ten common defects [7] that were assessed were (1) cracks, (2) weak branch union, (3) stem or branch decay, (4) cankers, (5) dead trees, top, and branches, (6) root problems, (7) poor tree architecture, (8) termite attack, (9) parasite or mistletoe.

In the sonic tomography measuring system, the PiCUS sonic tomography (Argus Electronic GmbH, Germany) was used in this study. Tomography measurement was carried out at the diameter’s breast height (dbh) or about 130 cm above ground level. Eight to twelve sensors spaced regularly were put in around the circumference of the cross-sections which were connected to the nails as a measuring point for detecting the transit time among those measuring points. The sound was generated by knocking the nail using an electronic hammer (figure 1). After knocking all the nails, a tomogram was created for each cross-section that was processed by the PiCUS Q7.2 software which was installed on a computer connecting to the sensors. Principally, sound travels at slower speed in decayed wood compared to solid or intact wood. Image from tomogram revealed color gradation which pointed out the condition of the interior part of the tree. Brown to black color indicated solid wood, green color was as early decay and decayed indication, and violet or blue color indicated advanced decay, cavity or cracks (figure 2).

Figure 1. Setting up equipment and generating the sound using a PiCUS sonic tomography.
3. Results and discussion

Totally 345 trees from 4 locations were investigated and analysed. The number of species identified were 23 tree species (table 1). Dominant species found were the Trembesi (41%), followed by the Flamboyan (20%), and the Sengon (8%) (figure 3).

![An example of a tomogram and the result of speed of sound among the sensor.](image)

**Figure 2.** An example of a tomogram and the result of speed of sound among the sensor.

### Table 1 Tree species identification in the study.

| No | Local name | Scientific name<sup>a</sup>                          | No | Local name | Scientific name                      |
|----|------------|-------------------------------------------------------|----|------------|--------------------------------------|
| 1  | Trembesi   | *Samanea saman* (Jacq.) Merr.                         | 13 | Kemenyan   | *Styrax* spp.                        |
| 2  | Flamboyan  | *Delonix regia* (Hook.) Raf.                          | 14 | Sulastri   | *Calophyllum soulatri* Burm.f.       |
| 3  | Sengon     | *Paraserianthes falcata* (L.) I.C.Nielsen             | 15 | Nyatoh     | *Palaquium calophyllum* (Teijsm. & Binn.) Pierre ex Burck |
| 4  | Mahoni     | *Swietenia mahagoni* (L.) Jacq.                       | 16 | Pinus      | *Pinus merkusii* Jungh. & de Vriese Thuja spp. |
| 5  | Sawo       | *Manilkara kauki* (L.) Dubard                        | 17 | Cemara     | *Michelia champaca* L.               |
| 6  | Kenanga    | *Artocarpus heterophyllus* Lam.                       | 18 | Cempaka    | *Mangifera odorata* Griff.           |
| 7  | Nangka     | *Hevea brasiliensis* (Willd. ex A.Juss.) Müll.Arg.   | 19 | Kuweni     | *Cocos nucifera* L.                 |
| 8  | Karet      | *Khaya anthotheca* (Welw.) C.DC.                     | 20 | Kelapa     |                                       |
| 9  | Palem Bismarkia | *Bismarckia nobilis* Hildebr. & H.Wendl. | 21 | Cemara susun | *Araucaria heterophylla* (Salisb.) Franco |
| 10 | Angsana    | *Pterocarpus indicus* Wild.                           | 22 | Asam Keranji | *Dialium indum* L.                    |
| 11 | Khaya      | *Sandoricum koetjape* (Burm.f.) Merr.                 | 23 | Ketapang   | *Terminalia catapa*                  |
| 12 | Kecapi     |                                                        |    |            |                                       |

<sup>a</sup>Source: http://www.theplantlist.org/
Figure 3. The distribution of tree species.

Visual evaluation is part of tree inspection and is a basic method. It was conducted by assessing the tree as a whole and examining the certain parts of the tree for defects from the top of the canopy, branches, stems, to the bottom of roots. The examples of tree defects found and assessed were shown in figure 4. Referring to [7] the crack is the condition where the wood is split or there is a gap between the bark and wood which usually found in stems and branches. Weak branch union is the form of a fork which is found in the stem and known as an included bark with a V-shaped connection. This condition unsounds structurally when more bark is included in the tree and the decay develops in that location. The stem or branch decay occurs due to fungi which infects the bark and wood and degrading the wood compound causing less structural strength and stability. Cankers is wood deterioration caused by fungi, insects or mechanical damage such as burn-wounds which leads to a dead area of bark and cambium. Canker by rot fungi infection is an extensive decay because it can inhibit the tree’s efforts to make compartmentalization and it causes the wood to weaken structurally. The dead tops or branches may remain attached to live trees but it is commonly easy to break off. When the tree or part of tree in the top falls down those parts might become structurally unsound. The root problem is mostly due to by mechanical disruption and the vigor of the root condition which is caused by fungal root rots. It becomes a serious problem when related to the tree’s stability such as the leaning tree, root severing, and missing root system. Poor tree architecture is the imbalance condition due to growth pattern mostly caused by pruning activity, too many branches arising from a single location, as well as a codominant tree form. Termite infestation in a tree is mostly conducted by subterranean termite species which consume the wood. Their nests are in-ground surface or underground and make tunnels or shelter tubes along the stem. They make the shelter on walls and other structures to provide protection from potential predators, especially ants. The certain species such as the Coptotermes curvignathus is very dangerous because they eat wood very fast. Parasite or mistletoe is parasitic plants that for a long time can strangle trees until it can kill the tree.

From the study, the visual assessment found that tree defects which often appear in the tree were dead tree tops and branches as well as twigs (27%), followed by poor tree architecture (20.4%), and stem or branch decay (18.3%) as revealed in figure 5. The higher the number of tree defects of dead main branches and also twigs should be a concern from landscape management since these parts often fall and can be harmful to the environment. Matthek and Breloer [3] mentioned that the two most common whole-tree failure types are tipping (uprooting) and fracture (breaking of stem or branches).
Figure 4. The example of a common defect found in trees.
An advanced inspection was carried out using sonic tomography. This equipment was used for
detecting the condition of the trunk. The category of tree health for the trunk was built based on the
solid wood percentage from the tomogram image. This category was derived considering the decay in
the trunk related to the tree structure and wood strength, especially the presence of the opening and
invisible cavities and advanced decay. The percentage of solid wood in the tomogram depicts the part
which remains in intact condition. The percentage of solid wood > 80% was in the sound tree health
category, solid woods were 50-80% in the moderate category, and < 50% were in an unhealthy
condition of the trunk. Unhealthy condition of the trunk should be closely monitored to determine the
change in internal condition. Figure 6 displays the number of trees in various trunk condition
categories.

![Figure 5. The percentage of the listed common defects found in trees.](image)

![Figure 6. The frequency of a tree in various tree trunk conditions based on the percentage (%) of solid wood from tomogram.](image)
Figure 7. several conditions depicted by the tomogram image and visual examinations: (a) solid wood percentage in the tomogram image 43% (left), visual tree appearance (right), (b) solid wood percentage in the tomogram image 71% (left), visual tree appearance (right), (c) solid wood percentage in the tomogram image 97% (left), visual tree appearance (right).
The category of the tree trunk’s condition is actually to simplify the meaning of solid wood percentage from the tomogram. Referring to various methods in calculating the loss of wood strength such as the Wagner method [8], the Smiley and Fraedrich method [9], and the Mattheck and Breloer method [2], they mostly stated that the threshold loss is approximately 30% of the strength and should be a concern related to the proportion decay in the trunk. It was recognized that the load bearing was in the outer part of the trunk. From the total 345 trees that have been inspected, 288 trees (83%) were in healthy or sound tree trunk condition, 43 trees (12%) in moderate condition, and only 14 trees (4%) should be intensively monitored since the internal tree trunk had less solid wood percentage (< 50%). Figure 7 displays several conditions depicted by the tomogram image and visual examinations. The conformity appears from the weakened location areas in the image which corresponded to the visual assessments. Nevertheless, van Wassenaer and Richardson [10] emphasized that the simplified formula would not yield reliable results from the symmetrical or irregular shape of the stem because there was a difference outlook on the decay on the outside and in the inside. For that reason, it is important to adjust the geometry shapes in inputs on the software. Since the recommendation on targeted trees was for the whole condition of the tree, with the purpose of the visual assessment which was complemented by the sonic tomography technology, better recommendations in tree inspection could be suggested in terms of the action of final decisions.

4. Conclusions

The tree defects frequently found in several public landscape areas in Jakarta were dead branches and twigs (27%), poor architecture (20%), and stem or branch decay (18%). In this study, three categories of the main tree trunk condition were developed based on the percentage (%) of the solid wood at diameter breast height (dbh) or about 1.3 m from the ground using PiCUS sonic tomography results i.e. healthy or sound, moderate, and unhealthy tree trunk condition. The study indicated that on the targeted tree, most of the trees were in healthy condition (84%), whilst 12% were in moderate condition, and as well the other few suffered with unhealthy condition (4%). Sonic tomography as an advanced assessment complements the visual tree assessment which could be useful in tree condition inspection as well as to consider the tree structure condition. The concerns on the crown condition especially the branches and twigs as well as the tree architecture should be improved as they often cause accidents to the target. The routine inspection in detail should be developed not only through visual assessment but also monitoring using recommended technology to assure the entire condition of the tree.

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