

Research of the Technology for Reducing the Load of Yarding

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ABSTRACT

Satoyama provide a variety of services and are symbolic of the coexistence of people with nature, so their conservation is to be desired. HELLO WOODS' is a facility that Honda maintains as a place for people to experience nature. Here, we perform conservation initiatives and receive benefits from the woods in return.

This research uses HELLO WOODS' as a case study in Satoyama conservation. Technology was developed to reduce the environmental burden of yarding; that is, moving trees after they have been logged (cut down).

This technology uses a small crawler-type power carrier and has an unmanned carrier function, overturn suppression function through sloping areas and loading/unloading function.

An experimental carrier was built and used to confirm that each function worked as required. These functions could reduce the burden created by yarding and help to conserve Satoyama.

1. Introduction

Since ancient times, humans coexisted with the natural world by taking resources from nature in moderation and maintaining sustainable ecosystems. The forests that people maintained for the sake of their livelihoods were referred to as Satoyama. Satoyama provide a number of services: fuel and other resources, biodiversity, disaster reduction, cultivation of water resources, environmental conservation, scenery, and a place for environmental education.

However, since the use of fossil fuels became widespread in the period of high economic growth, people began to leave the Satoyama unmaintained, as they did not feel that the Satoyama's services made them worth maintaining from an economic perspective. The Satoyama gradually changed as a result, forming dark forests thick with brush and filled with bigger trees.

In collaboration with workshop participants, Honda has taken part in Satoyama conservation initiatives at HELLO WOODS', a facility, located within Honda's Twin Ring Motegi, where people can come to experience nature. These initiatives realize Satoyama services by keeping up the cycle of raising trees and then logging them for use. Satoyama are maintained as young, bright forests as shown in Fig. 1, because they are periodically logged. The logged trees are then used as firewood, charcoal, and the like. Conservation tasks include practices that establish the forest like cutting grass and vines as well as harvesting work like tree logging and yarding.

Out of all of these, the most burdensome task is yarding.

The purpose of this research is to reduce the burden of yarding when performed by ordinary persons with little yarding experience. The aim was to establish technology to lower the burden of yarding, using HELLO WOODS' as a case study. If a technology with lower burden were to become widespread, it would allow more people to get involved in conservation initiatives in Satoyama other than HELLO WOODS' and more Satoyama could be conserved.

This paper suggests functions to reduce the burden of yarding, gives an overview of an experimental carrier that the



Fig. 1 Satoyama in HELLO WOODS' (Provided by HELLO WOODS')

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researchers built in order to meet established requirements, and discusses how the technology and performance were verified.

2. Work Analysis and Targets to Achieve

Yarding refers to transporting harvested trees (i.e. logs) from the logging area to the place where they are collected (called a log yard). For this study, the researchers began by examining the nature of the work and the burden that it creates at HELLO WOODS'.

The log yard at HELLO WOODS' uses a small crawler-type carrier, called Honda Power Carrier. At the logging area, logs are cut into appropriate lengths in a process called bucking. The bucked logs are manually loaded onto the Honda Power Carrier, then a person operates the Honda Power Carrier to make it travel through the logging area and over logging roads, finally unloading the logs at the log yard. Annually, 0.4 ha of Satoyama trees harvested this way at HELLO WOODS' is yarded by repeating the above process again and again.

The researchers' study found that yarding creates three types of burden. The first is that forest roads are traveled over repeatedly in order to carry the logs. As they operate the carrier, human operators have to walk back and forth over sloping logging roads that were built on uneven terrain. The longer the distance, the more time and human strength the process requires. The second burden is that carriers traveling on sloping ground are susceptible to overturning. To help prevent overturning while traveling over the roads, carriers can only be loaded with less than half their maximum capacity of logs, which increases the number of trips required. The third burden is the loading and unloading of heavy logs. Logs weighing between 20 and 35 kg make up about half of this burden by weight. On a questionnaire given at the workshop, many respondents said that loading and unloading logs was the most physically challenging aspect of the work. To alleviate the three burdens above, the objective was to build three functions as shown in Fig. 2: the use of unmanned carriers, overturn suppression, and loading and unloading support. These are described below.

(1) Unmanned carrier

Unmanned carrying allows workers to do other tasks and is very efficient. It also reduces the physical burden on the worker, who no longer needs to walk long distances.

This is done by a carrier that automatically travels a pre-established route as it carries the logs. Because trees in a Satoyama create interference that makes GPS unusable, this was done in two ways. The first is electromagnetic navigation. This approach assumes that the carrier will travel an unchanging route between two log yards. It will be able to do so even in rain or snow. The second approach is visual navigation. This is anticipated when carrying logs from the logging area, which changes every year. With this approach, routes can be changed with minimal work.

(2) Overturn suppression

With the use of overturn suppression, loading the carrier

with many logs for travel through sloping logging areas reduces the number of trips to and from the log yard. It also minimizes the number of detours around sloping areas. These increase work efficiency.

The shape of the crawler's footprint on the ground makes it more unstable from side to side than from front to back. Therefore, this function was designed to reduce the likelihood of overturning to the side. Additionally, Satoyama contain ancient roads referred to as "three-shaku roads," which are just 90 cm wide.

Building wider roads would be environmentally damaging, so this is not an appropriate option if Satoyama conservation is the goal. The researchers therefore worked to suppress overturning to either side while maintaining a size small enough to let the carrier travel over these narrow roads. To this end, the carrier was built with a swing drive mechanism to suppress overturning. This lets the carrier balance its center of gravity as it travels.

(3) Loading and unloading support

A small crane is used to load and unload logs. Although this can reduce the physical burden, operating the crane is complex: ordinary controllers like levers and buttons are used to move the crane in three dimensions (back and forth, up and down, left and right). A person not used to such controllers will work much less efficiently. There is also a risk of accidents if controllers are operated incorrectly.

The function was therefore developed to enable easy operation with an interface that directly manipulates the movement of the logs, and to make it easy for even those unaccustomed to yarding work to load and unload without any great drop in efficiency.

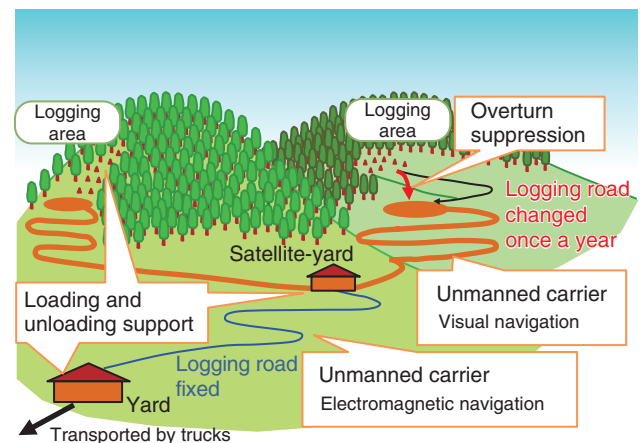


Fig. 2 Three functions for logging in Satoyama

3. Experimental Carrier and Verification Items

This part discusses the experimental carrier used to verify the functions, and the items that were verified.

Table 1 Experimental carrier specifications

	Experimental carrier	Honda Power Carrier HP500
Length	2090 mm	2030 mm
Width (cargo bed)	850 mm	Max. 900 mm
Surface area of the grounding of unilateral crawler belt	180 mm × 694 mm	180 mm × 694 mm
Weight of carrier and max. load	703 kg	542 kg
Max. velocity (forward)	2 km/h	4.3 km/h
Max. angle of rise	20°	15°
Type of drive of crawler	2 Motors	Engine
Power source	Li-battery	Gasoline

3.1. Experimental Carrier

The experimental carrier was based on the Honda Power Carrier HP500. It was given an electric drive system and equipped with mechanisms, sensors, and drive systems for the three functions. It also has a system controller to control all functions. Specifications of the experimental carrier equipped with the three functions are given in Table 1. The maximum velocity while traveling takes into account the speed while yarding in HELLO WOODS'.

Figure 3 is a diagram of the electric system of the experimental carrier with the three functions, and Fig. 4 is a photograph of the experimental carrier that the researchers built.

The crane for loading and unloading support is located next to the cargo bed and has a boom long enough to allow it to clamp onto logs around the bed. While the experimental carrier is traveling, the boom folds up and is stowed at the side of the vehicle. The camera used for visual navigation is located opposite the cargo bed, with an arm

in between, to help prevent it from making contact with the logs. During unmanned carrying, the camera side is in front as the carrier travels.

3.2. Verification Items

To test the unmanned carrier function, it was verified whether the carrier can travel over a test course within the error requirements described below. To test overturn suppression, it was verified whether the carrier can travel the test course while loaded. To test loading and unloading support, it was verified whether the amount of time needed to load and unload with this function satisfies the requirements described below.

Figure 5 shows the test course that was set up to test the unmanned carrier and overturn suppression functions. The course reflects the characteristics of roads used to perform yarding in HELLO WOODS'. A circuit about 50 m long was used to check the unmanned carrier function. A traverse road surface was separately laid out to verify overturn suppression.



Fig. 4 Experimental carrier

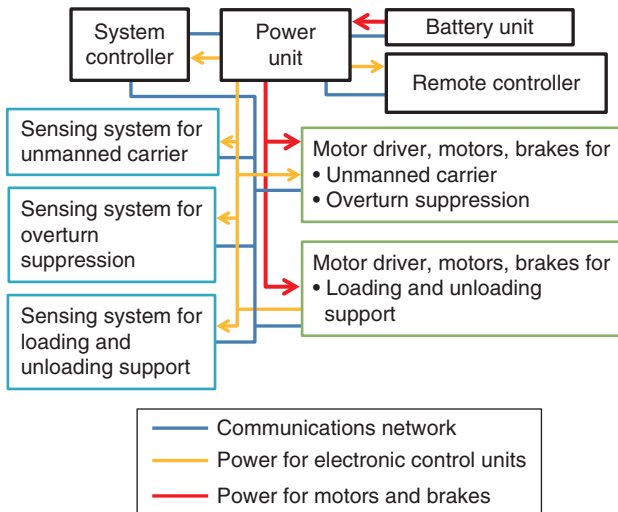


Fig. 3 Electric system of experimental carrier

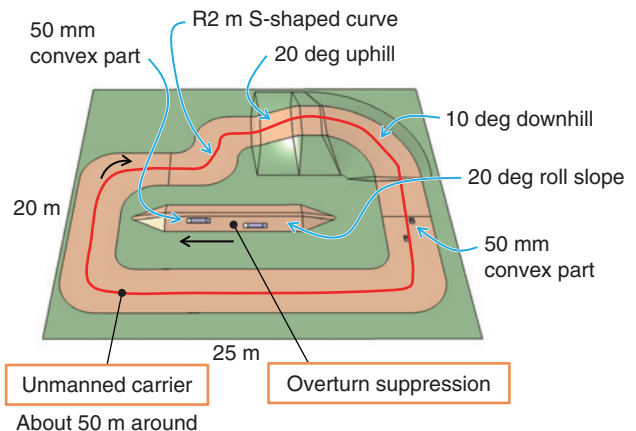


Fig. 5 Test course

4. Major Technologies and Achievements

4.1. Electromagnetic Navigation

The logging road over which the carrier traveled was 900 mm wide, with maximum roll angle of 7° and maximum surface asperity of ±50 mm. These values were based on “three-shaku roads” and the road surface conditions found in HELLO WOODS’. The same conditions were used for testing visual navigation, as described below.

Because the carrier travels over uneven terrain, the sensing system had to work not only with lateral but also vertical positional change between the guide cable and onboard sensors. The usual technique for dealing with positional change, which focuses on lateral positional change (as used in golf carts), is greatly affected by the detection distance to the guide cable in the lateral direction as a result of vertical positional change. For that reason, the experimental carrier is also designed to deal with vertical positional change.

4.1.1. Functional requirements

During unmanned carrying, the crawler, which is 600 mm wide, travels over a road that is 900 mm wide in the straight sections, as shown in Fig. 6. Therefore, the maximum allowable position error during travel is ±150 mm. The minimum radius at corners on the logging road was set at a turning radius (R) of 2 m in the center of the road. At R 2 m points, 1100 mm was set as the logging road width, which is the width that the Honda Power Carrier is able to travel while working conventionally. Table 2 shows the maximum allowable gap between the position of the guide cable and the center of the road; the maximum position estimation error for the experimental carrier in respect to the guide cable; and tracking error. The velocity requirement is the ability to travel at least 2 km/h on straight sections.

4.1.2. Technology achieved

As it traveled, the experimental carrier used its magnetic sensors to detect the magnetic field generated by the guide

Table 2 Required range of position error

No.	Factor of position error from center of road	Required range of position error from center of road [mm]	
		Straight road	R2 m curved road
1	Gap of laid cable and center of road	±50	±120
2	Position estimation (Included in No.3)	±60	Not setting
3	Trajectory tracking control	±100	±130
Lateral margin (No.1+No.3)		±150	±250

cable laid down the middle of the logging road, thus estimating its own position. The carrier stopped when it detected a stop position, which was created by placing a magnetic field shield board over the guide cable.

The carrier’s magnetism detection system consisted of two magnetism sensors, one vertical and one horizontal, whose axes were perpendicular to each other. This arrangement allowed the system to detect the distance to the guide wire in both the lateral and vertical directions. This configuration is called a cross sensor module.

The guide cable contained transmitters that produced the same current pattern repeatedly at regular cycles. Each time this current pattern occurred, an induced electromotive voltage peak induced in the coil in the magnetic sensor was detected. Combined vector V_P of induced electromotive voltage peak as detected by the vertical sensor (V_{VP}) and induced electromotive voltage peak as detected by the horizontal sensor (V_{HP}) is inversely proportional to distance from guide cable (r) and proportional to the peak of first-order differentiation of current, as in Eq. (1), as Ampere’s law makes clear. Here, V_{VP} and V_{HP} are the values shown in Eq. (2), and horizontal distance y and height z are derived as in Eq. (3). The value of constant C as used in Eqs. (1) through (3) was identified by experimentation. The two experimental carriers built showed some magnetic field distortion owing to variability in the metal of the vehicles, so detection results were not the same. Therefore, C was identified so that the amount of error in detection distance would be the same in both carriers.

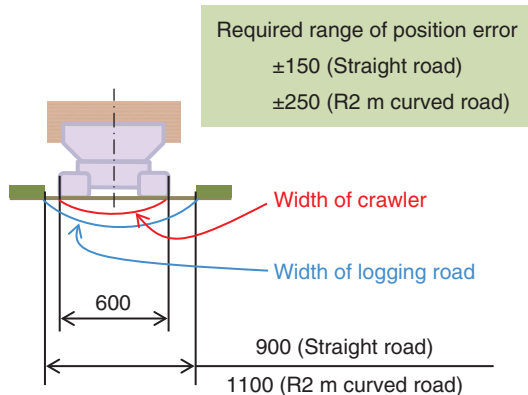


Fig. 6 Width of carrier and logging road

$$V_P = \frac{C}{r}, \quad C = \frac{\mu NS}{2\pi} \cdot \left(\frac{di}{dt} \right)_{\text{peak}} \quad (1)$$

$$\begin{cases} V_{VP} = \frac{C}{r} \cdot \frac{y}{\sqrt{y^2 + z^2}} = \frac{Cy}{y^2 + z^2} \\ V_{HP} = \frac{C}{r} \cdot \frac{z}{\sqrt{y^2 + z^2}} = \frac{Cz}{y^2 + z^2} \end{cases} \quad (2)$$

$$\begin{cases} y = \frac{CV_{VP}}{V_{VP}^2 + V_{HP}^2} \\ z = \frac{CV_{HP}}{V_{VP}^2 + V_{HP}^2} \end{cases} \quad (3)$$

Cross sensor modules were affixed to the front and back of the carriers as shown in Fig. 7 to control travel. Each module provided y , the horizontal distance between the guide cable and vehicle center; and φ , the angle between the guide cable and vehicle. The turning velocity Ω_c^{ref} was given and forward velocity V_c^{ref} was set at a uniform value to calculate the lateral crawler velocity.

The carrier automatically stopped when the value of detected height z from Eq. (3) was detected as exceeding an established threshold value. This occurred when the magnetic field reaching the cross sensor module was weakened by a magnetic field shield board, as shown in Fig. 8.

4.1.3. Verification results

Table 3 lists error factors associated with cross sensor modules when they are mounted on carriers and the maximum error as measured during testing of properties.

Table 3 Tolerances measured about each factor

No.	Factor of position estimation error	Error estimate [mm]
1	Slope of cross sensor module (roll 10 deg, pitch 10 deg, yaw 20 deg)	± 12
2	Electromagnetic strain (max measured value of 2 carrier-bodies and 4 sensors)	± 28
3	Measurement error in calibration	± 5
4	Electromagnetic noise	± 4
5	AD convert and arithmetic error	± 2
6	Others	± 3

Table 4 Position error of automatic traveling

	Straight road [mm]	R2 m curved road [mm]
Required range of position error	± 100	± 130
Test result	± 35	± 43
Consider a production tolerance of carrier and sensor	± 63	± 71

The maximum amount of error of mounted cross sensor modules was ± 54 mm, which is the sum of all errors.

The carriers were able to travel over the test course with this technique. Figure 9 shows a carrier traveling with navigation by electromagnetic navigation. Because the vehicle was traveling on the same course as used with visual navigation, visual navigation marks as explained in the next section were placed along the course. The amount of error during trajectory tracking control was found by using a ruler to measure the distance between the crawler track and guide cable and converting. As Table 4 shows, traveling results satisfied the allowed error requirements indicated in Table 2, No. 3. The carriers even satisfied the requirements when magnetic distortion caused by vehicle variability is considered.

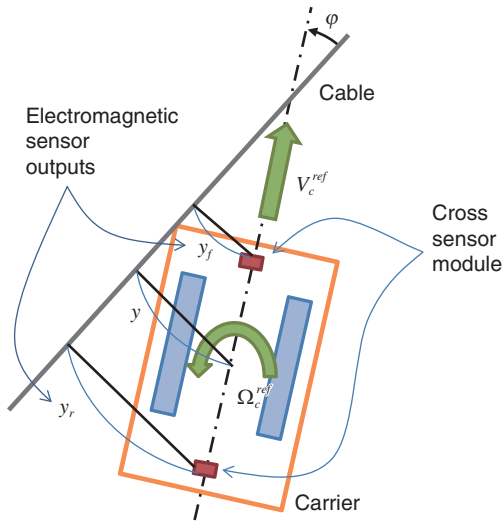


Fig. 7 Position of carrier and sensor output

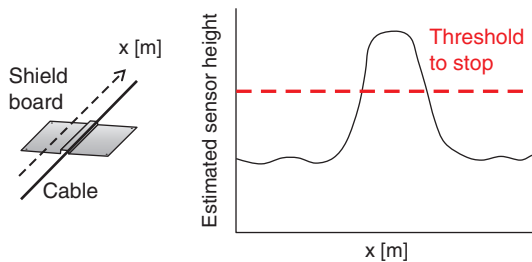


Fig. 8 Automatic stop by shielding magnetic field



Fig. 9 Automatic traveling by electromagnetic navigation

4.2. Visual Navigation

From sunrise to sundown, and throughout the four seasons, the optical environment of the Satoyama will vary, as will the condition of the plants that provide landmarks. Therefore, it is a challenge to achieve very robust position estimation. For that reason, the technique used was to set artificial marks around the course to help ensure that the carrier reliably detects its position; that is, its position in respect to those marks. Additionally, automatic traveling by teaching playback was used to enable the carrier to travel any trajectory: ordinary travel, stopping, switchbacks, and so on.

4.2.1. Functional requirements

The traveling precision requirements in respect to road width were the same as with electromagnetic navigation. Table 5 shows the maximum error allowed for each factor. Allowed errors during teaching travel were decided based on the operability of the experimental carriers. Additionally, position was estimated both during teaching travel and trajectory tracking control, and therefore the visual system position errors of the two, as in the table below, are added together, making double that amount.

4.2.2. Technology achieved

In order to achieve stable estimates of position, this technique combines results of position estimation using visual sensors with results of position estimation with internal sensors.

The locations of marks for estimating position by visual sensor were first tentatively decided based on camera angle of view and the form of the course. Then, the experimental carrier was allowed to travel the course, and as it did so the researchers confirmed which positions it was able to detect, and they adopted those positions. Estimating position with visual sensors requires that at least two mark positions are detected at all times. As Fig. 9 shows, marks were placed alternately on the left and right sides of the road in straight lines with intervals of about 0.7 m. At the curves, they were placed on the outer side at intervals of about 0.9 m. Retroreflective material was applied to the marks at a certain rate in the long direction. The infrared beam from a projector was reflected toward the camera at high intensity.

The visual sensor was a stereo camera using a difference camera⁽¹⁾, which made it possible to separate light from the projector from light in the environment. As a result, the system was able to extract the mark image in a short period of time, using only light from the projector. To enhance the intensity of reflected light, it is necessary to reduce the distance between projector and camera. One projector was placed on each side to correspond to the left and right cameras. Stereo cameras can offer enhanced precision when they have longer baselines, and in this case, the length was set at 0.3 m, the farthest distance they could be placed apart on the carrier.

The major processes that happen when estimating

Table 5 Required range of position error

No.	Factor of position error from center of road	Required range of position error from center of road [mm]	
		Straight road	R2 m curved road
1	Operation by user in teaching phase	±50	±100
2	Position estimation in teaching phase (Included in No.4)	±25	±25
3	Position estimation in playback phase (Included in No.4)	±25	±25
4	Trajectory tracking control	±100	±150
Lateral margin (No.1+No.4)		±150	±250

Table 6 Features of position estimation by each sensor

	Processing Time	Noise	Drift
Position estimation by visual recognition	Large	Large	Small
Position estimation by inner sensors	Small	Small	Large

position with visual sensors are: (1) reading the image, (2) detecting the marks, (3) performing stereo operations, (4) finding the uncorrected position, (5) correcting the position, and (6) outputting the corrected position.

Marks are detected by the visual sensors, which are used in combination with the technique of calculating position. Acceleration and angular velocity sensors and a crawler velocity detector (i.e. internal sensors) are also used, then position is estimated by integration. Table 6 shows features of position estimation by each type of sensor. The table suggests that visual sensors offer better position estimation in the low-frequency range while internal sensors do better

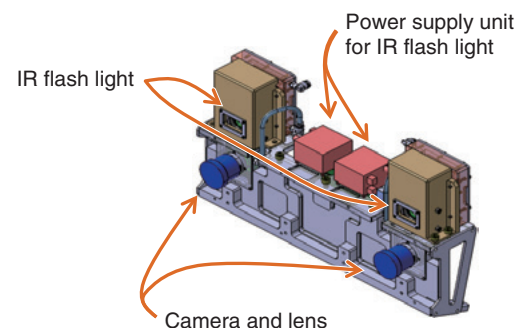


Fig. 10 Stereo difference camera unit

in the high-frequency range. To take advantage of these features, the position estimation system designed here uses a low-pass filter on carrier position as found by the visual sensors and a high-pass filter on carrier position as found by the internal sensors, and combines the two. This is illustrated in Fig. 11. The result is stable position estimation.

During trajectory tracking control, crawler velocity during teaching travel is used as a feedforward term, while the deviation between travel trajectory during teaching travel and current position is used as a feedback term, to calculate velocity command values for the left and right crawlers.

4.2.3. Verification results

First, the precision of the visual system's position detection was evaluated. Because the system is both a teaching and trajectory tracking control system, tracking precision in respect to the teaching trajectory is required, but absolute locational precision is not important. For that reason, the visual system is evaluated according to the variance in detected position (i.e. the visual system position error) when the carrier travels the same trajectory. Moreover, this variance is attributable to variance in visual sensor output.

Four visual system output variables are used to verify precision: X, Y, Z, and θ_z . θ_x and θ_y , which are not used for control purposes, are excluded. Thus, the amount of displacement was checked by setting the camera system upon an X - Y - Z - θ_z table as shown in Fig. 12, and moving/rotating the table as the reflective marks were being detected. Figure 13 shows the visual system position error on the Y axis when there has been camera displacement along the Y axis at the furthest position on the X axis at which detection is assumed to occur. These results show

that, under the strictest conditions, the visual system position error (3σ) is ± 7.7 mm, meeting the pre-established requirement of ± 25 mm.

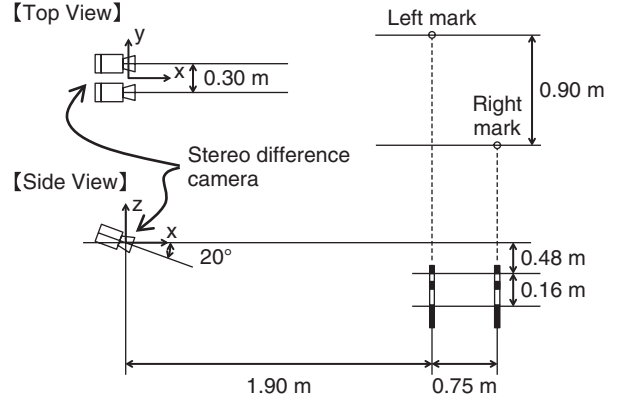


Fig. 12 Bench for measurement of locational error of visual recognition

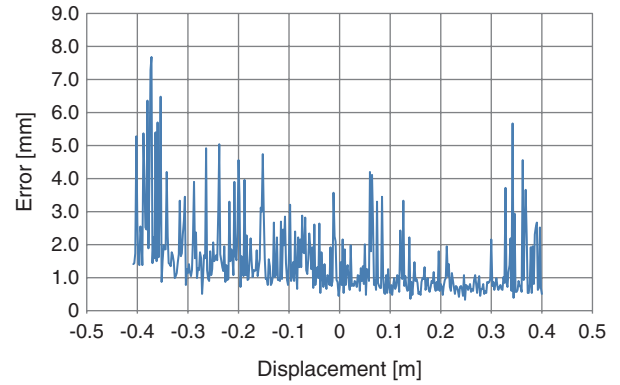


Fig. 13 Locational error of visual recognition

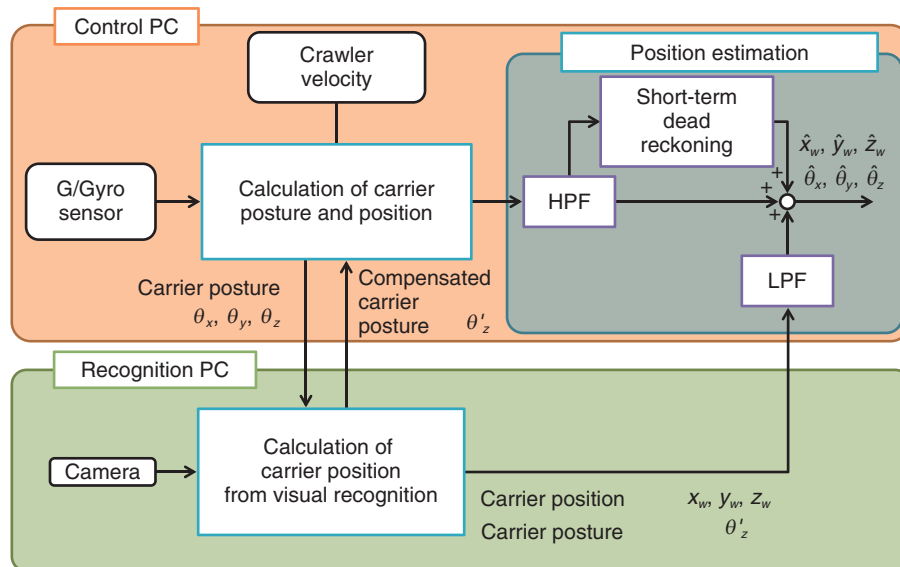


Fig. 11 Process of integration position estimation

Table 7 Position error of automatic traveling distance from teaching orbit

	Straight road [mm]	R2 m curved road [mm]
Required accuracy	± 100	± 150
Test result	± 15	± 40

The carriers were able to travel over the test course with this technique. Table 7 shows the deviation from the teaching trajectory during trajectory tracking control. The results showed that the carrier satisfied the allowed error requirements indicated in Table 5, No. 4.

4.3. Overturn Suppression

The overturn suppression technology assumes that the carrier will mainly travel through the logging area. The maximum slope for the carrier to travel in the logging area was set at 20° . It was assumed that on slopes of greater than 20° , workers would roll the bucked logs until they come to a 20° slope.

4.3.1. Functional requirements

The functional requirement was that the carrier be able to travel, while loaded, on road surfaces with asperity of ± 50 mm maximum on slopes with a maximum roll angle of 20° .

4.3.2. Technology achieved

For the sake of attitudinal stability, the carrier consists of two parts: the chassis and cargo bed. A lateral swing drive is activated to maintain balance in the center of gravity. A slope sensor affixed to the cargo bed detects the cargo bed's roll angle. Feedback control is used so that the roll angle goes to 0° , that is, horizontal.

To maintain balance in the center of gravity between left and right and ensure travel stability, the swing drive mechanism's center of rotation has to be close to the road surface. As Fig. 14 shows, when there is a high center of rotation, the center of gravity in the cargo bed does not

change very much. Even if swing drive is activated, the zero moment point (ZMP) is likely to go beyond the tread as in (1) so that the overturn suppression function does not work. The ZMP is the point over the road surface where the horizontal component of the combined moment of inertia and gravity generated by motion around that point is zero. In (2), even if the ZMP is within the treads, there is a difference in the amount of grip force between left and right, making it a challenge for the carrier to move straight ahead. In (3), the cargo is susceptible to collapsing as a result of the axis of rotation swinging left and right.

Thus, the experimental carrier was built as in Fig. 15 with a multi-joint mechanism and an arched rail to keep the center of rotation low. As a result, the virtual center of rotation within the swinging axis was 90 mm from the road surface.

4.3.3. Verification results

This technique made it possible for the carrier to travel 1.5 km/h on a road with 50 mm bumps and roll angle of 20° . Figure 16 shows the upper-side crawler traveling over a 50 mm bump on a 20° slope.

ZMP was used to evaluate attitude stability. Figure 17 shows a model of the ratio of ZMP on tread during travel. The experimental carrier's tread was set at 420 mm, which is the distance between the longitudinal centers of the left and right crawlers. When the ZMP is at the center of one of the crawlers, the ZMP's positional ratio y_{ZMP} is 1.

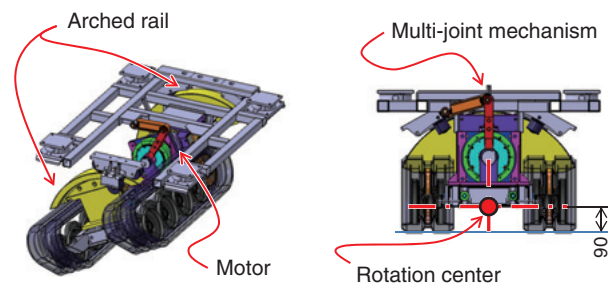


Fig. 15 Swinging mechanism with arched rails

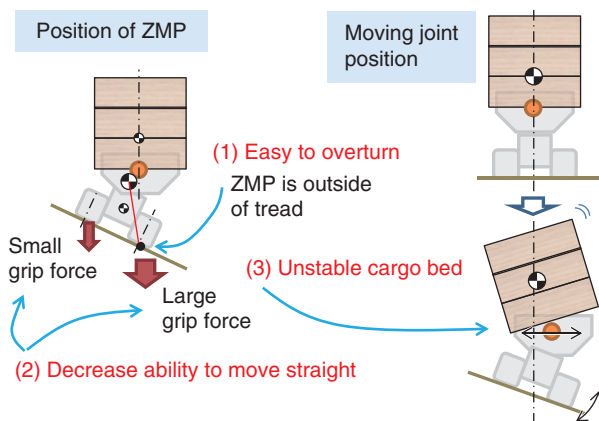


Fig. 14 Harmful effect of high position of joint



Fig. 16 Traveling on slope using overturn suppression

Figure 18 shows travel data from the experimental carrier with overturn suppression function together with results of simulation using vehicle parameters assuming that the vehicle does not have this function. In the case of the carrier with overturn suppression, the ZMP stays within the tread range, indicating that there is sufficient stability. The carrier without overturn suppression could possibly overturn because the ZMP fluctuates beyond the tread range.

4.4. Loading and Unloading Support

For the purpose of this study, the maximum log weight was set at 35 kg, because the survey results indicated that logs weighing 35 kg or less make up 80% of the total weight of logs loaded and unloaded. Also based on survey results, log length was set at 70 cm. Logs weighing more than 35 kg were to be bucked to shorter lengths to keep their weight at 35 kg or below. The requirement for slope of roads on which the carrier would work was set at a maximum of 20°.

4.4.1. Functional requirements

A requirement was set for loading and unloading time, because one objective of this function is easy operation.

Results of the workshop survey indicated that the average time required to load or unload a log is 13 seconds. In consideration of the fact that other objectives are to alleviate burden and help prevent any great loss of work efficiency, the requirement for allowable loading and unloading time was set at 20 seconds per log. Moreover, because the other two functions enable efficiencies during transportation work,

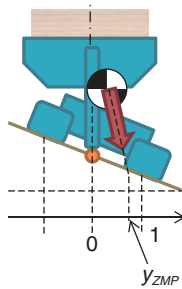


Fig. 17 Ratio of ZMP on tread

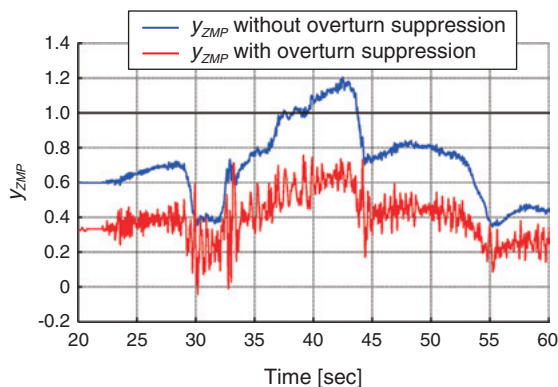


Fig. 18 ZMP on traveling on slope

it is still possible to achieve greater efficiency overall, even if there is some loss of efficiency as a result of this function.

4.4.2. Technology achieved

Loading and unloading with the small crane are performed on slopes, so the boom has to be able to turn and move up and down. A motor was provided for each of these movements. Reeling the wire in and out is also done by means of a motor.

A stable hold can be maintained if the tip of the boom supporting the wire follows a grip held by the operator, staying over it. Data on the wire's inclination is input and the boom position is controlled to track the grip so that the boom follows the grip and the wire hangs straight down. A method that refers to the velocity and force at the grip would not be appropriate here, because twisting of the wire makes it challenging to determine the attitude around the yaw of the grip. Moreover, with a method that refers to the force of the wire on the boom tip, gravitational force cannot be separated from force generated by user operation of the equipment when using it on a slope. Therefore, two components of the relative angle with the wire and the vertical direction (i.e., pitch axis and roll axis) are taken as input values for following control. The boom's pitch axis target angle is calculated based on the relative angle of the pitch axis, while the boom's yaw axis target angle is calculated based on the relative angle of the roll axis, and thus there is feedback control. At the same time, the amount of wire reeled out is controlled in conjunction with the boom pitch drive so that the grip is at a constant height. Additionally, the system is designed so that following control only occurs when the operator pushes a button on the grip. This helps prevents unintended activation of the boom. The grip also has a controller to move the boom up and down, which is a way of reeling the wire in and out independent of following.

The mechanism for sensing the inclination of the wire is shown in Fig. 19. It was designed so that the wire would form a tangent in relation to the pulley at all

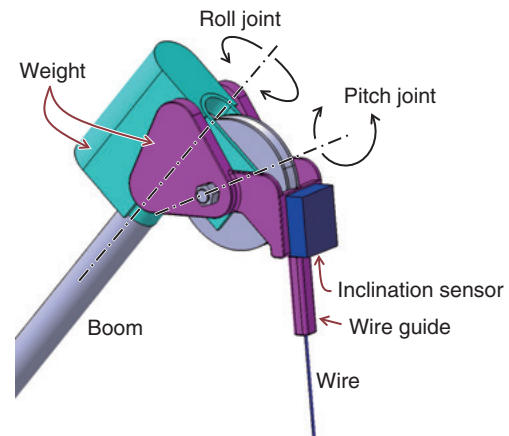


Fig. 19 Guide mechanism for sensing inclination of wire

times so that the inclination of the wire could be detected with two degrees of freedom and the impact of the wire's tension could be reduced. Moreover, to reduce self-induced vibration by the pendulum element resulting from the mass of the wire guide and inclination sensor, weight was allocated to each axis so that the center of gravity was positioned close to the axis of rotation.

Furthermore, since the crane was to hold logs 70 cm long, the range over which logs can be picked up was extended 400 mm beyond the cargo bed perimeter, and the boom length was set at 2020 mm, as shown in Figs. 20 and 21.

4.4.3. Verification results

This technique made it possible to load and unload logs through direct operation. Figure 22 shows an operator performing the work with the crane.

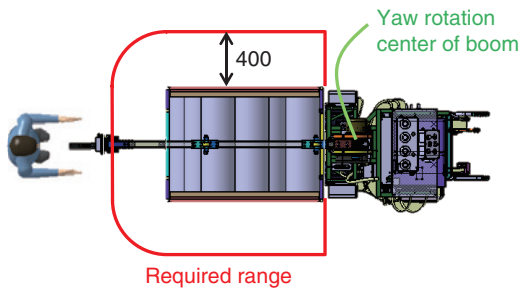


Fig. 20 Required range for picking up logs

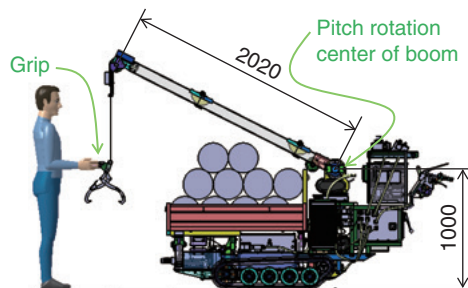


Fig. 21 Crane design of loading and unloading support



Fig. 22 Loading and unloading support

Additionally, in order to determine how well this function performs, the researchers found the shortest possible time needed to load and unload. The prescribed actions of loading and unloading are as described below and shown in Fig. 23. (a) As the work begins, four logs are on the ground around the carrier, (b) the logs are loaded into the cargo bed, and (c) the logs are placed side by side next to the carrier. For both the loading and unloading stages, the work was divided into four steps and the time necessary for each was found: (1) move the grip to the log, (2) clamp onto the log, (3) move the log to the desired place, and (4) release the clamp on the log. For verification, four individuals each performed these tasks two times, and their time was taken.

The shortest sum of time needed to perform all the steps during loading was 17 seconds, which was also the shortest sum of time needed to perform all the steps during unloading. This clears the requirement of 20 seconds.

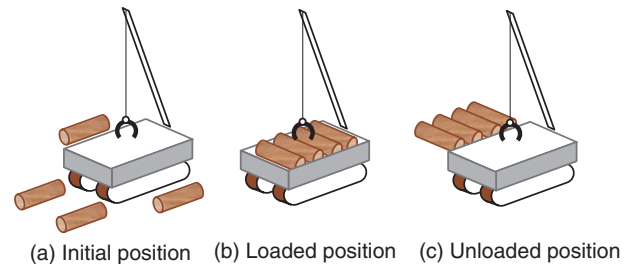


Fig. 23 Steps for measurement time of loading and unloading

5. Expected Benefits

The above functions and the requirements that they meet should reduce the burden of yarding work.

The researchers calculated the total work time (from start to finish of yarding work) and the worker hours (found by multiplying the number of workers with their work time) when the three functions were used. The calculation assumed that the work would be done by two workers and one carrier. The logging site was on 0.4 ha of sloping ground. The carrier traveled 2 km/h from logging area to log yard over a road 300 m long each way. The carrier made repeated trips back and forth. The time needed to perform each job and the amount carried were set based on the workshop survey, then calculations were made that considered the loss of efficiency owing to loading and unloading support. A carrier with the three functions is predicted to reduce total work time by 44% and total worker hours by 51% compared to a conventional carrier.

Moreover, total travel distance of the carrier over the logging road was 303 km with the conventional technique. The unmanned carrier therefore greatly reduces the physical burden on workers, who now do not need to walk that

distance. Even loading and unloading support does not greatly increase work time, but it does reduce the physical burden during loading and unloading work.

6. Conclusion

Using HELLO WOODS' as a case study, the researchers proposed three functions—use of an unmanned carrier, overturn suppression, and loading and unloading support—to conserve Satoyama and reduce the burden of yarding. Based on the HELLO WOODS' case study, they confirmed that the experimental carrier they developed met its requirements. Following is an overview and a description of the major achievements of each function.

(1) Unmanned carrier

When using electromagnetic navigation, equipping a carrier with a cross sensor module capable of dealing with uneven terrain, together with a guide cable on the road surface, allowed the carrier to travel and stop automatically.

When using visual navigation, a system equipped with a stereo difference camera together with marks around the course made it possible for the vehicle to travel by teaching playback.

(2) Overturn suppression

By using an arched rail to effectively stabilize attitude, the researchers achieved an attitude stabilization mechanism that controls the tilt of the cargo bed.

(3) Loading and unloading support

To make crane operation easy, the researchers built a mechanism that detects wire inclination and an activation control system that keeps the wire vertical at all times.

A test course was laid out for this research and used to find the basic performance of each function. Actual yarding sites present complex environments, so it is predicted that various issues will occur. Verification of whether the configuration and requirements associated with each function are appropriate will have to be done at actual yarding sites.

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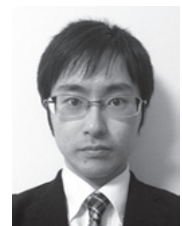
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