

Development of UNI-CUB

Wataru YADA*

Yoshiki TATSUTOMI*

Makoto HASEGAWA*

ABSTRACT

Honda has been engaging in development efforts aimed at new personal mobility that allows people to move in harmony with others in indoor spaces, facilities, and other such places where there are people coming and going.

In 2009, Honda announced the U3-X, in 2012 the UNI-CUB, and then in 2013 the UNI-CUB β .

All these are personal mobility devices capable of movement in all directions, which are also sit-on style, inverted pendulum-type, compact devices that fit between the rider's legs.

This paper describes the technological evolution of the UNI-CUB, which uses the Honda Omni Traction Drive System adopted since the U3-X that enables movement in all directions. This paper will also introduce the implementation in society of this new form of mobility known as the UNI-CUB. The demonstration tests carried out with the National Museum of Emerging Science and Innovation starting in June 2012.

1. Introduction

Research on the inverted pendulum control model was already being conducted in the 1970s in the field of human body engineering called biomechanics. Together with theoretical analysis of a uniaxial inverted pendulum, work at the demonstration level was carried out using models⁽¹⁾⁻⁽³⁾.

A quarter of a century ago in 1989, in advance of the rest of the world, two inverted pendulum-type vehicles (uniaxial type driven by two parallel wheels, biaxial type driven by a single sphere) were exhibited at the Idea Contest, an in-house event at Honda R&D Co., Ltd. This attracted attention in Japan from many people in different areas of endeavor⁽⁴⁾⁻⁽⁶⁾ (Fig. 1). The uniaxial vehicle was subsequently commercialized by Segway Inc. in December 2001, and it has come to be recognized as a new form of mobility^{(7), (8)}.

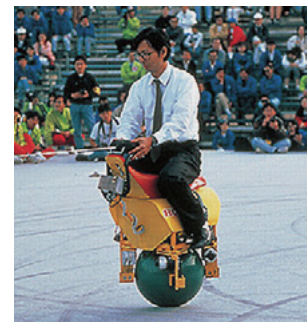
Meanwhile, the biaxial type driven by a single sphere has continued to undergo research and development for practical application in recent years⁽⁹⁾⁻⁽¹¹⁾. Having devised a proprietary drive wheel that applied an omnidirectional wheel for the drive mechanism, Honda began developing mobility that strongly appealed to people.

Aiming for a personal mobility device that provides for movement in harmony with other people in indoor spaces, facilities, and other such places where there are people coming and going, Honda announced the U3-X in 2009. In

order to make the vehicle rideable by a wider range of age groups, both men and women, and in more locations, further technical development was carried out. While the U3-X is characterized by Honda Omni Traction Drive System (HOT drive) and balance control technology, the UNI-CUB also has another wheel added in the rear to allow easier turning. The resulting more evolved vehicle was named the UNI-CUB⁽¹²⁾. The following will introduce the technological evolution of the UNI-CUB in 2012 and UNI-CUB β in 2013 and the aspects of demonstration tests using the UNI-CUB β .



(a) Single-axis type



(b) Dual-axis type

Fig. 1 Original mobility devices with inverse pendulum

* Smart Mobility Development Division

2. Research and Development Leading to the UNI-CUB β

The balance control technology cultivated through the ASIMO bipedal walking robot research and the HOT drive, which allows all direction movement, were combined in research and development of a new personal mobility device that enables riders to alter their speed and movement in any direction at will by inclining their body to shift their weight. The U3-X (Fig. 2, Table 1) was announced in 2009 as a show model that would verify the value of this approach.

During development of the U3-X, the aim was to come up with a personal mobility device that could harmonize with the rider as well as with the surrounding people and satisfy the following product requirements:

- (1) Easy hands-free operation and movement
- (2) Easy foot-to-ground contact for rider's sense of security against over-turning
- (3) Compact size to fit within width of a person's body
- (4) Same eye level as surrounding pedestrians

The next model of UNI-CUB was developed for the purpose of use in demonstration tests started in 2012. The aim was to realize operation so intuitive for the rider that it would enable freedom of movement similar to that of a person walking. The personal mobility was successfully developed that enables rotating motion as well as movement forward, backward and side to side with a size compact enough to fit between a person's legs (Fig. 3, Table 2).

In order to further enhance the practical usability of the UNI-CUB β , the results of the UNI-CUB demonstration tests were provided as feedback, and development addressed the following issues accordingly:

- (1) Compact, lighter in weight
- (2) Design to further enhance the sense of unity of the user and the device
- (3) Exterior design that is soft to the touch in order to make the seat more comfortable and have an affinity to surrounding people.

The result was announced in 2013 as a business demonstration model (Fig. 4, Table 3).

Table 1 Specifications of U3-X

Size (L × W × H) (mm)	315 × 160 × 650
Seat height (mm)	650
Battery type	Lithium-Ion Battery
Maximum speed (km/h)	6
Duration time (hour)	1

Table 2 Specifications of UNI-CUB

Size (L × W × H) (mm)	520 × 345 × 745
Seat height adjustment range (mm)	745 - 825
Battery type	Lithium-Ion Battery
Maximum speed (km/h)	6
Range (km)	6
Application environment	Barrier-free indoor environments

Table 3 Specifications of UNI-CUB β

Size (L × W × H) (mm)	510 × 315 × 620
Seat height (mm)	620
Battery type	Lithium-Ion Battery
Weight (kg)	25
Maximum speed (km/h)	6
Range (km)	6 (approximately 1.5 hours at speed of 4 km/h)
Application environment	Barrier-free indoor environments



Fig. 3 UNI-CUB



Fig. 2 U3-X



Fig. 4 UNI-CUB β

3. Proprietary UNI-CUB Technology

Figure 5 shows an external view of the UNI-CUB.

The device body is structured with the HOT drive that serves as the front wheel supported by an axle on the lower part of the seat frame on the UNI-CUB body. A swing-arm extending to the rear from the axle is interposed between that wheel and the rear wheel, which serves as the turning wheel for the omnidirectional wheel (Fig. 6). The front wheel produces driving power that can move it forward and backward and side to side, and functions to move and balance the device body. The rear wheel functions solely to turn the device body.

3.1. The HOT Drive Principle

The principle of HOT drive movement is characterized by the exterior appearance, shown in Fig. 7, of a large-diameter wheel with multiple small-diameter free rollers positioned around its periphery. Internally, it has a drive disc positioned on either side, and around their periphery are free rollers (hereafter, drive rollers) positioned at angles one to the other. The structure of the drive is such that these drive rollers press against the free rollers on the large-diameter wheel, causing both the large wheel and the free rollers to rotate.

Driving the left and right drive discs at the same angular velocity (in the same direction of rotation) stops the axial

rotation of the small-diameter free rollers, leaving only the axial rotation of the large-diameter wheel in operation. This causes the device body to move longitudinally. Conversely, driving the left and right drive discs at opposite angular velocities (in the opposite direction of rotation) stops the axial rotation of the large-diameter wheel, leaving only the axial rotation of the small-diameter free rollers in operation. This causes the device body to move laterally. When the left and right drive discs are run at different angular velocities (magnitude and direction), a compound axial rotation of the large-diameter wheel and small-diameter free rollers is generated, enabling movement in a diagonal direction.

This principle was applied in the HOT drive, which was adopted for use in the UNI-CUB.

3.2. Balance Control Technology

An advanced control system was constructed that responds to the behavior of the center of gravity of the device body and the rider seen as a single body. That center of gravity is changed by the rider's shifting center of gravity. The left and right drive discs take that change as a command value relating to the rider's movement intentions and operate accordingly while simultaneously stabilizing the rider's position. The speed and direction of movement, longitudinal or lateral, constitute command values that are read from the amount of relative displacement of the rider's center of gravity from that of the device. Balance control to stabilize the rider's position takes signals from the device body acceleration sensor and angular velocity sensor as input. The control drives the HOT drive wheel forward and backward and from side to side and functions to generate an appropriate restoring force against tilting (Fig. 8).



Fig. 5 External view of UNI-CUB

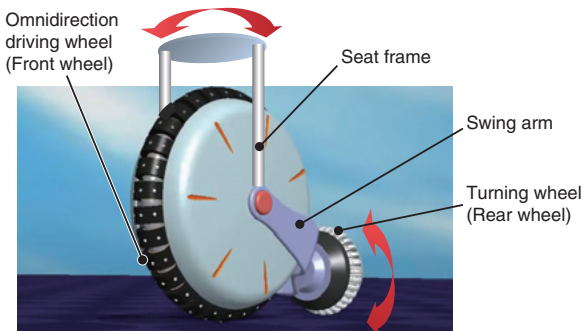


Fig. 6 Drive train with omnidirectional wheels

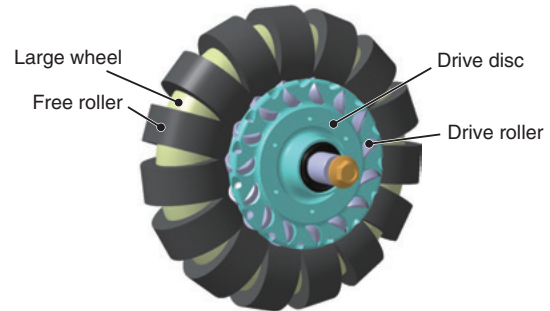


Fig. 7 Principle of HOT drive system

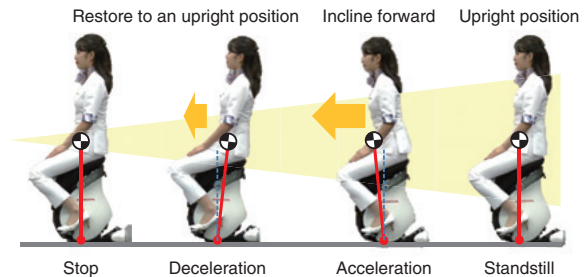


Fig. 8 Balance control

4. Evolution of the UNI-CUB

4.1. Necessity of a Turning Function

The U3-X had only the HOT drive as a drive source and had a single point of contact with the ground. Given its construction, it is not capable of generating yaw moment (moment around the axis perpendicular to its contact point with the ground), and so it is unable to turn on its own. In order to cause it to turn, therefore, the rider would touch a toe lightly to the ground, as shown in Fig. 9. The U3-X could then use that contact point with the ground as a pivot for turning. The need for this operating technique meant that ordinary people could not readily operate the U3-X.

These issues were addressed by adding a turning wheel to the UNI-CUB to give it a turning function. The turning wheel is a drive wheel with a structure like that of the HOT drive large-diameter wheel, with multiple free rollers placed around its periphery. The wheel and rollers are controlled by detecting the difference in the lateral speed of movement between the front and rear wheels and generating a turning angular velocity, as shown in Fig. 10.

With movement control implemented by the addition of



Fig. 9 U3-X turning procedure using toe

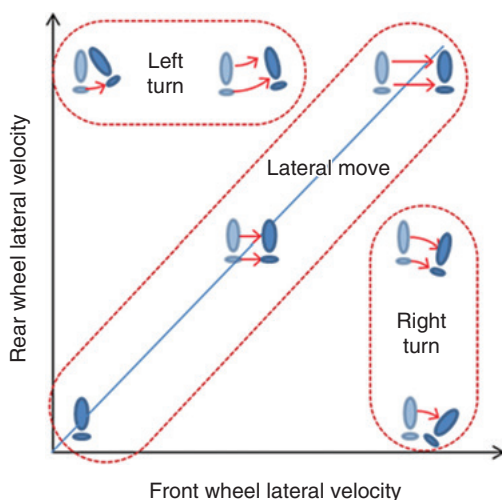


Fig. 10 Schematic diagram of lateral movement and turning

a turning wheel, smooth transitions from forward movement to turning and from sideways movement to turning were achieved by the rider leaning the upper body to shift the body weight while the device is moving. This enables turns.

4.2. Relationship between Forward Movement and Turns

In order to achieve a smooth transition from forward movement to a turn, the rider leans the upper body to the side while the device is moving forward. The shift in body weight not only causes the device to turn, but also starts a sideways movement. Under the initial control configuration, however, the orientation of the device body during a turn was toward the outside of a line tangent to the turn circle, and this caused some discomfort because the direction of the turn was not readily visible. Repeated organoleptic evaluations were therefore conducted of the device body's response characteristics with regard to shifts in the rider's body weight. This led to adoption of characteristics such that when the forward speed is greater, the ratio of the angular velocity of the turn to the sideways shift in body weight becomes higher. Figure 11 is a schematic diagram showing the relationship between forward speed, the sideways shift in body weight, and the angular velocity of the turn.

This realizes operability matched to the rider's intentions across the entire speed range, from low to high.

4.3. Relationship between Sideways Movement and Turns

In places such as art museums, there is a need to be able to move sideways at a slow pace when viewing paintings that are lined up on the walls. When moving to another exhibition area, there is also a need for riders to be able to change the direction of movement and the orientation of the device body toward the direction of movement by inclining their body weight farther to the side while in motion. Realizing actions like these required control that balanced the sideways movement gain and turning gain.

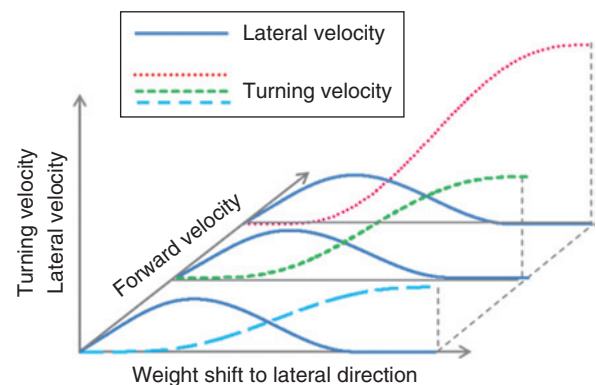


Fig. 11 Schematic diagram of turning motion generation (Velocity-dependent)

Figure 12 shows a schematic diagram of the relationship between turning angular velocity and lateral velocity with respect to the rider's lateral weight shift. This is movement realized by the control implemented in this device.

When the lateral weight shift is smaller, the device simply moves sideways without turning. The control is configured so that when the lateral weight shift is greater, the device moves in a combination of sideways movement and turning. The device body response characteristics were configured so that when the lateral weight shift grows still larger, the device only turns. This realized the kind of movement desired in art museums and other such locations, and conveyed the desired impression with that movement.

4.4. Addressing Barrier-Free Requirements

The environment of use envisioned for the U3-X (Fig. 2) was interior space with flat floors. Indoor barrier-free spaces with tactile paving blocks or other such uneven surfaces designed to provide guidance were not envisioned. When demonstration tests were conducted, it was found that the device performance had to allow traversal of 5-mm differences in level. The dimensions of the large-diameter wheel, the small-diameter wheel, and the gear making up the HOT drive (Fig. 7) were modified to enhance the ability of the device to traverse differences in level.

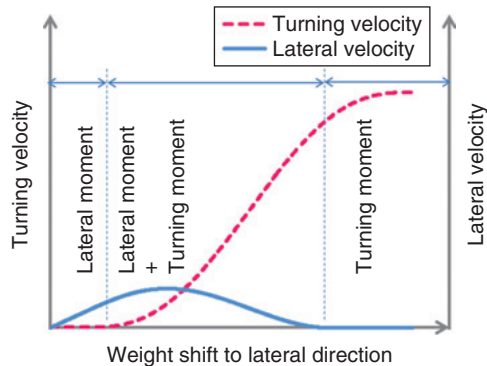


Fig. 12 Schematic diagram of turning motion generation

5. Joint Demonstration Tests with the National Museum of Emerging Science and Innovation

Following the announcement of the UNI-CUB, joint demonstration tests with the National Museum of Emerging Science and Innovation (Miraikan) were begun in June 2012⁽¹³⁾.

Honda's objective was to verify the concept of personal mobility that harmonizes with people. The mission of the National Museum of Emerging Science and Innovation,

on the other hand, was to provide for new knowledge to be shared between society and researchers. These joint demonstration tests were therefore agreed to by the two parties as having substance that was to the benefit of each. For example, it was demonstrated that people who were unable to complete a long guided tour on foot because they grew too tired became able to complete the tour using the UNI-CUB.

The tests were designed and carried out to enable verification of harmony with people in graded stages, as described below.

5.1. UNI-CUB Use in Stage Demonstration

First, Science Communicators (SC) at Miraikan conducted 15-minute demonstrations to communicate the characteristics of the UNI-CUB to visitors (Fig. 13).

The stage was laid out so that visitors could watch at close quarters. The SC riding the UNI-CUB would move close to the viewers to ask them their impressions and so on, with actions that allowed confirmation of a sense of friendliness on both sides.

5.2. UNI-CUB Use in Making Rounds of the Museum and for Guide Operations

SCs used the UNI-CUB to make rounds of the museum interior as well as in guide operations with visitors. These were the first times for the UNI-CUB to move in among the visitors, and confirmed that people sensed a quality of affinity with the device, such that approximately one-half of those who crossed paths with the UNI-CUB did not immediately notice it.

This approach to use of the device allowed acceptance by the people around it without any sense of discomfort, confirming its quality of affinity. It was also observed that a natural dialogue came into being with visitors to the museum.

5.3. Five-Minute Trial-Ride Sessions

Short trial-ride sessions were held for visitors. There



Fig. 13 Scene of UNI-CUB demonstration at an exhibition

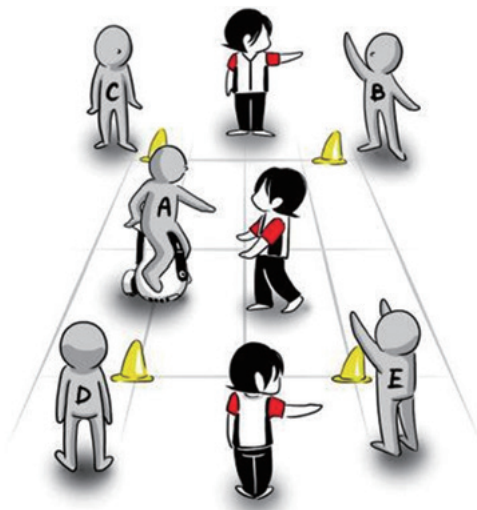
were 89 participants in all spanning the wide range of ages from 11 to 81. The trial-ride sessions were held in groups of five participants, with each group assigned one UNI-CUB. The trial-ride time allotted each person was five minutes. Care was taken to allow participants to feel how the UNI-CUB moves in response to the direction a rider looks, the action of pointing, and other such natural weight-shifting actions. With this approach, almost every participant learned how to operate the device within the given time. The four participants other than the rider were asked to stand at a reasonable distance around the rider to acquire a natural feeling for how the device and people harmonize with one another [Fig. 14(a), (b)].

Figure 15 shows the results of a questionnaire given to trial-ride participants. The content covered three items of affinity with surroundings, ease of controlling the movement of the mobility device, and sense of security. These were rated by five-level evaluation as excellent, good, fair, poor, and very poor. Even though the trial rides of five minutes were very brief, respondents gave high marks for

sense of affinity with surroundings and ease of controlling the movement of the mobility device, confirming their acceptance of the UNI-CUB concept.

5.4. Museum Tour Experience for Visitors

Tours for visitors were held in which they used the UNI-CUB to see the museum exhibits (Fig. 16). The time taken by the tour, including the questionnaire and related matters, was approximately one hour. The tours were organized in groups consisting of several visitors, each guided by one SC. Comments from visitors who experienced the tour confirmed that use of the UNI-CUB allowed people to concentrate more on the exhibits than if they walked

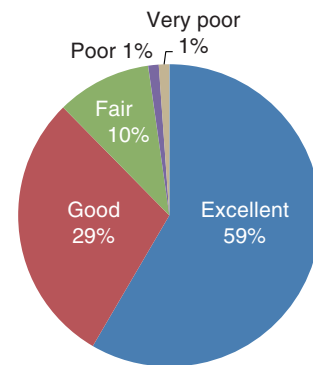


(a) Illustration of training method

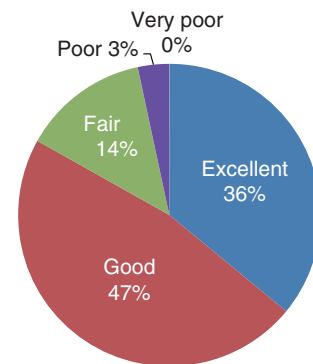


(b) Photo of training scene

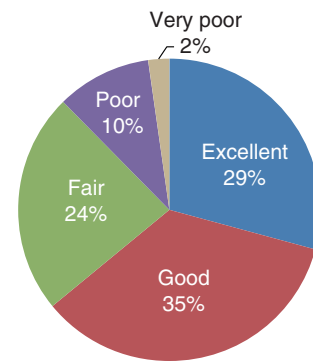
Fig. 14 Test area for 5-min. trial ride experience



(a) Sense of affinity with surrounding people



(b) Ease of controlling mobility device



(c) Secure feeling

Fig. 15 Questionnaire results

through. Some participants also commented that the time they spent seemed to go faster than the time actually taken on the tour.



(a) Scene of riders in motion



(b) Scene of visitors enjoying exhibits

Fig. 16 Guided tour

6. Activities with the UNI-CUB β

Following Honda's announcement of the UNI-CUB β at the 43rd Tokyo Motor Show in November 2013, the device was exhibited at motor shows throughout Japan. Large numbers of visitors had the opportunity to experience the device.

Leasing of UNI-CUB β devices to Miraikan, Honda Cars Osaka, and others for use was begun subsequently as an experiment in for-pay business.

Based on experiences of this kind, UNI-CUB β use has been expanded to guided tours for exhibitions in various parts of Japan. This use is presently underway (Fig. 17).

Miraikan started employing these devices in April 2014, for SCs to use in making rounds. In October, the museum opened a UNI-CUB Station (Fig. 18) and started renting out the devices for trial-ride tours. The tours being provided, on a paid basis, are Miraikan introductory tours providing trial-ride experience of certain zones in Miraikan, and permanent exhibit tours that take participants around

the permanent exhibit floor with explanations by an SC.

A music video made by the popular American rock band "OK Go" in October 2014 featured the UNI-CUB β . The video was viewed worldwide (Fig. 19). Use in this kind of application was beyond expectations.



Fig. 17 Scene of UNI-CUB units on standby at an exhibition



Fig. 18 UNI-CUB station



Fig. 19 Scene from "OK Go" music video

7. Conclusion

Honda has been working for some time to develop mobility devices that harmonize with people. The U3-X in 2009 announced the concept of achieving pedestrian-like movement using Honda's proprietary HOT drive mechanism. The UNI-CUB with further enhanced operability was subsequently used in 2012 to conduct demonstration tests at Miraikan in which the device was implemented in society. In 2013, the UNI-CUB β was announced. This model incorporates the results of demonstration tests in a more compact package that can be used by a wider range of riders. In 2014, Honda successfully started testing UNI-CUB leasing for business.

As the device continues to gain more widespread recognition, its growing dissemination can be anticipated to bring a variety of uses, as seen by its employment in a music video.

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■ Author ■



Wataru YADA



Yoshiaki TATSUTOMI



Makoto HASEGAWA