ICT-based Judging Support System for Artistic Gymnastics and Intended New World Created Through 3D Sensing Technology

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The elderly is estimated to make up almost a third of the Japanese population by 2020. Led by the Japan Sports Agency, one of the ministries and agencies related to sports in Japan, initiatives have been launched to make sports one of the country's major industries in collaboration with the healthcare and health promotion fields. Given that the sports business is a big industry overseas, the Japanese government aims to grow the sports market to 15 trillion yen by 2025. 3D sensing technology is drawing attention in the sports IoT area, which is considered important for this market expansion. Fujitsu is pursuing the development of 3D sensing technology to build a judging support system in collaboration with the International Gymnastics Federation and Japan Gymnastics Association. This paper describes the value and new world to be created through Fujitsu's 3D sensing technology, and our efforts to standardize it internationally.

1. Introduction

In Japan, the elderly is expected to make up 29.1% of the population by 2020. This figure is projected to reach 33.4% or about one third of the nation by 2035.[1)]

Under these conditions, increases in healthcare costs and other social security expenditures are becoming a major problem. As a result, society is becoming increasingly aware of "sports," "nutrition," and "social participation" as three key elements for extending healthy life expectancy. The government is also becoming active in this regard, and a movement toward making sports a major industry in Japan is being launched under the guidance of the Japan Sports Agency, one of the ministries and agencies related to sports in Japan, established in 2015 in collaboration with the public and private sectors, healthcare and health promotion fields, etc.

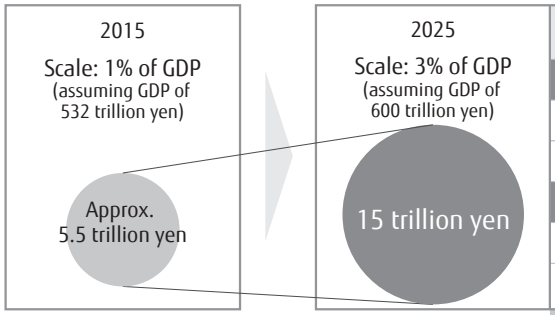
Viewing sports as a promising industry, the United States and various European countries have been actively investing in a variety of sports-related areas such as professional sports leagues, stadium/arena facility development, and health and physical-fitness markets. As a result, the sports business has become a giant industry in those countries, and with this in mind, the Japanese government has set expansion of the Japan sports market from 5.5 trillion yen in 2015 to 15 trillion yen by 2025 as a national target (**Figure 1**).[2)]

The technology that is generating great expectations as a driver of this market expansion is IoT. The government projects the emergence of a new sports IoT market on a scale of 1.1 trillion yen. 3D sensing is attracting particular attention in the sports IoT area. Fujitsu is working on the development of 3D sensing technology to support gymnastics judging as a co-creation project with the International Gymnastics Federation (FIG) and Japan Gymnastics Association (JGA).

In this paper, we describe value creation through 3D sensing technology, future directions of this technology, and efforts to establish international standards for 3D sensing.

2. Sports IoT today and current issues

Initial attempts at data visualization using sensors have already been made at past international sporting events in such competitive events as boxing, volleyball, archery, and taekwondo. In boxing, for example, sensors have been used for measuring a punch's strength and type, its speed and direction, the



Field	2025	Increase
1) Stadium/arena	3.8	+1.7
2) Professional sports	1.1	+0.8
3) Amateur sports	0.3	+0.3
4) IoT use	1.1	+1.1
5) Peripheral industries	4.9	+3.5
6) Sporting goods	3.9	+2.2
Total (trillion yen)	15.2	+9.7

* Prepared based on References 2), 3)

Figure 1
Government targets for the sports market.

number of punches, etc. and the data obtained could be used for improving an athlete's training regimen. In volleyball, data visualization has been used to measure the height and number of jumps and to improve players' competitive ability such as by reducing load on the knees to prevent injuries. Furthermore, to ensure fairness in judging, it has been used in archery to measure the correct position of an arrow embedded in the target and in taekwondo to assess kicks using sensors attached to protectors.

From here on, we can expect that visualizing various information using IoT will be tested and introduced in all sorts of competitive events. There is a great need, in particular, for capturing the movement of the human body in three dimensions in real time. Up to now, "motion capture" has been the mainstream technology for recording human and object movement in the form of digital data. This technology captures motion by using 20–30 reflective markers somewhat smaller than ping pong balls attached to the body's surface near joints and taking measurements with multiple light-equipped high-precision video cameras. Thereafter, 3D data is obtained through compensation processing performed by an operator. However, attaching reflective markers to the body can be a burden to the athlete while playing or performing. As a result, motion capture has so far been mainly used in R&D environments because of this difficulty in using it during practice sessions or actual matches.

In order to overcome the above difficulty, Fujitsu has successfully developed 3D sensing technology for measuring movement of the human body in real time without the use of markers. This technology combines 3D laser sensors developed for automobiles and joint position recognition software developed for rehabilitation by Fujitsu Laboratories. Fujitsu is promoting various studies on applying this technology to artistic gymnastics and other areas in the field of sports.

This 3D sensing technology oscillates many lasers on a scale of about 2 million points per second, detects the reflected light, and calculates the distance to the target object for each point to obtain the 3D shape of the object (point cloud). It then recognizes the joint positions from this shape, calculates hands and feet positions, bending of joints, etc., and finally compares those results with model data of human movement in a database to derive differences in movement. In this way, it becomes possible to check body positions and angles as numerical data and to conduct analyses from all directions, 360 degrees around the target in a judging support application, which were difficult to achieve with ordinary camera images (**Figure 2**).

3. Gymnastics today, current issues, and reasons for its selection

On setting out to apply 3D sensing to sports, we first conducted interviews with people associated with various types of sports. As a result of these interviews, we concluded that the best sport to begin this application of 3D sensing would be artistic gymnastics, on the basis of the needs from athletes, judges, and spectators and also from dissemination of its technologies.

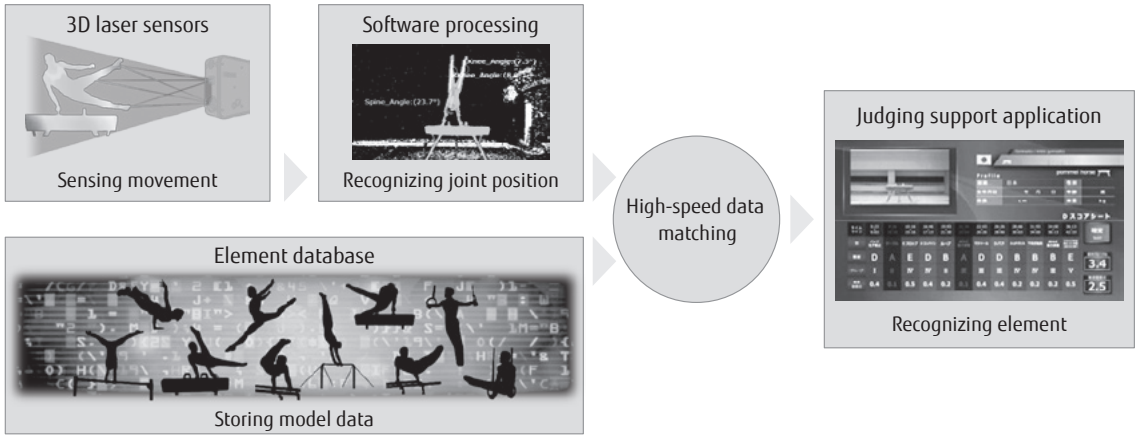


Figure 2
Overview of 3D sensing technology.

Unlike competitive sports like track and field and swimming in which athletes compete in terms of time or distance, gymnastics includes scored competitions in which points are awarded for a performance (human movement). In recent years, however, gymnastic elements have become increasingly complicated with high-speed movements, and as a result, there have been an increasing number of cases in which judges have trouble making a decision when scoring with the naked eye.

This limitation in visual observation arises not only in judges but also in the athletes themselves, spectators, and viewers. It can be said that overcoming this limitation is an issue common to all types of scored competitions in addition to gymnastics.

1) Athlete's viewpoint

Athletes and coaches have used video images for practice and guidance. However, since the data is not digitized, they cannot compare performances between good and bad forms of themselves or with those of another athlete's performance. For this reason, conventional training is qualitative.

2) Spectators' and viewers' viewpoint

At present, spectators and viewers have difficulty understanding elements or its judging criteria, but develop a somewhat understanding of it after hearing an explanation. In addition, according to the TV staff, judging takes a certain amount of time, so shortening that time makes for a more enjoyable viewing, and fitting it all into a television-broadcast timeframe (in most cases, two hours) results in more programs being broadcast.

In addition to these on-site issues and needs, Fujitsu placed importance on the following attractive points of gymnastics in selecting it for application of 3D sensing from the viewpoints of technology development and global expansion.

1) Compared to other sports, gymnastics features the most variation in human movement. It should, therefore, be possible to obtain an abundant amount of data and to build a database of movements with a high level of versatility that could be expanded to other sports.
2) Gymnastics is considered to be a sport that Japan is good at, and it is relatively easy to obtain the cooperation and extensive know-how of JGA and other concerned parties. Furthermore, for the overseas expansion of this 3D sensing technology, it is not difficult to obtain consents from the gymnastic associations in other countries. The FIG, one of the International Sports Federations (IFs), has the longest history among the many sports federations in existence. It is one of the three big IFs (gymnastics, track and field, and swimming) that have a huge impact on other sports associations.
3) In gymnastics, there are growing calls for fairness in judging at the international level. Adoption of the technology introduced in this paper would enable Fujitsu to become involved in the formulation of international rules and to contribute to the global standardization of this technology.

4. Development of judging support system through co-creation

In May 2016, JGA and Fujitsu concluded an agreement to conduct joint research on a judging support system using 3D sensing technology.[4] In this research, JGA provided judges' know-how, athlete data, and a test environment while Fujitsu developed a prototype system for judging support. In October 2016, a proof of concept (PoC) demonstration was held at a FIG congress and studies commenced toward the formal introduction of this technology. The prototype system consisted of 3D laser sensors and a high-performance personal computer, which was loaded with a data flow engine, joint position recognition software, a dictionary of elements, and a judging support application.

At the 47th FIG Artistic Gymnastics World Championships in Montreal held in October 2017, Fujitsu conducted a verification experiment using actual tournament data in cooperation with the FIG. On the basis of the results of this experiment, the FIG and Fujitsu announced a business alliance toward the development of a judging support system. Specifically, Fujitsu will collaborate with the FIG in the realization of a judging support system by developing a judging support application, building a database of elements (athletes' movements), and creating digital judging rules.

To build the database, Fujitsu will obtain athletes' performance data from competitions inside and outside Japan and store that data in units of basic motions that make up of a set of elements. The goal is to store data on 819 elements (combining 475 basic motions) from 6 men's apparatuses and 549 elements (combining 318 basic motions) from 4 women's apparatuses.

In addition, current scoring rules, "Code of Points", are described by athlete illustrations and vague expressions for judging. In this form, they cannot be implemented in an application for a judging support system. The digitization of scoring rules using a skeleton model having 18 joints is therefore a major feature of the proposed system. Code of Points has consisted of a set of elements illustrations and criteria for point deduction (such as "straight," "slight bending," "strong bending" etc.). To digitize scoring rules, we are creating a skeleton model that assigns a number to each joint. In this way, it could be stated, for example, that no points are deducted provided that the hip angle (the angle of the line connecting joints 4, 0, and 11) and the knee angle (the angle of the line connecting joints 0, 11, and 12) are greater than 170 degrees. We plan on creating scoring rules for all targeted elements (**Figure 3**).

Going forward, we plan to conduct an interoperability and operation test with the existing system at the

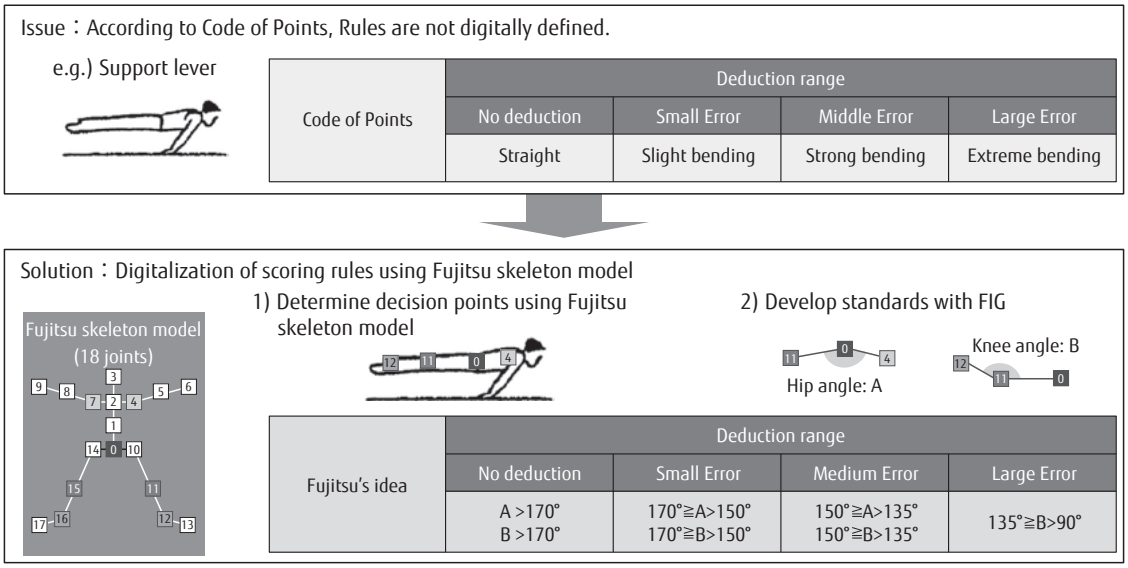


Figure 3
Digitization of elements.

48th Artistic Gymnastics World Championships in Doha to be held in 2018 and to actually operate the system at the 49th Artistic Gymnastics World Championships in Stuttgart to be held in 2019. We are aiming for an official adoption of this judging support system at a championship to be held in 2020 or later.

5. Leverage of 3D sensing information

To resolve on-site problems and needs in parallel with the development of the judging support system, Fujitsu is promoting studies on the development of a training system and production of content for broadcasting use. The aim is to provide value to athletes as well as spectators and viewers using information visualized through 3D sensing technology.

1) Training system development (co-creation with JGA)

In this project, we will use the judging support system to extract viewpoints that should be visualized in consultation with the coaching staff of JGA, which has successfully trained many medalists. We will also develop and implement an application capable of using that numerical data for instructional purposes. Looking to the future, our goal is to roll out this system to the national training facilities of 148 member countries of the FIG and to gymnastics associations in various countries for use by more than 900 teams.

To acquire an element in gymnastics, it is important to adopt a systematic, technical affinity approach to learning that takes progress into account. It can be said, however, that consolidation and analysis toward systematizing gymnastic elements has already been extensively pursued over the last 50 years. On the other hand, if such systemization could be resumed in collaboration with various organizations at co-creation sites, and if the analysis of correlations with training effects and other such studies can be promoted, we should be able to expect beneficial results such as the development of new elements and of exercise methods that avoid injuries.

2) Production of broadcast content

In this project, we will study the use of gymnastic athletes' 3D data obtained by 3D sensing technology to produce various types of broadcast content to convey the points awarded for their performance or amazing feats. We will also study means of delivering such content to television stations, network delivery operators, venue operators, etc.

At the Artistic Gymnastics World Championships in Montreal mentioned above and the All-Japan Team Championships held in November 2017, we conducted trials on providing television stations with information on the height of the highest point reached in vaulting. Our plan going forward is to hold discussions with gymnastics-related persons, directors, etc., with the aim of visualizing items of interest to spectators and viewers, such as the speed of aerial twists and flight duration, and of increasing the amount of content. The combining of such visualized data and video is being adopted in baseball, soccer, tennis, and other sports mainly in Europe and the United States as an indispensable means of enhancing the entertainment value of sports.

6. Approach to popularizing 3D sensing technology

As described above, we expect 3D sensing technology to provide new value to each of the sports-related needs (playing, watching, and supporting) of people and to have the effect of enhancing a person's sports experience. Additionally, as shown in **Figure 4**, we also expect it to improve the athletes' skills, make watching sports more entertaining, and contribute to an increase in spectators at stadiums/arenas and home viewers too.

What is the best approach to popularizing advanced technology like 3D sensing? We believe that it can be divided into the following three points. The first point is to establish a global standard for the technology. In the world of sports, this means developing the world's first judging support system using 3D sensing together with the FIG and to promote the revision of international rules and the global standardization of the technology.

The second point is to develop a training system based on that technology and to roll out content for broadcasting use on a global basis. If the judging support system were to become a new world standard, it would naturally follow that athletes would work to improve their abilities using a training regimen based on that system. Fujitsu seeks to develop a training system that merges the know-how possessed by JGA with AI and big data analysis technology and to contribute to Japan's medal count in this way. We also want to provide an environment in which all the people involved

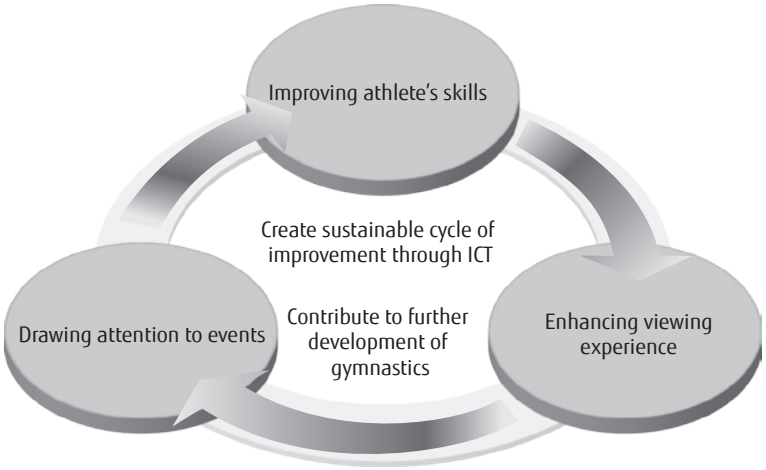


Figure 4
Virtuous cycle for stimulating the sports market.

with gymnastics in the world can enjoy the benefits of this training system. In this regard, some countries in Africa and elsewhere have a small number of gymnastics coaches. In response to this problem, the implementation of e-learning functions could meet the need for coaching in remote areas in these countries.

Fujitsu would like to achieve results in producing broadcast content through presentations at international sporting events such as FIG Artistic Gymnastics World Championships and FIG World Challenge Cup, and to connect such achievements to a global rollout of such sports content.

The third point is to expand training to athlete conditioning and rehabilitation. This includes the creation of a flow for using technology developed at development and production sites of apparatuses and sportswear. We can also expect the production of sports content to expand into neighboring fields such as movie production and the entertainment market. Additionally, we would like to create new application fields by passing on and disseminating industrial craftsmanship through the digitization of manual skills, creating a flow for using the developed technology in traditional performing arts, etc.

7. Fujitsu's role in sports field

Fujitsu attaches importance to the following three viewpoints in applying 3D sensing technology to the field of sports.

1) Human empowerment

The field of sports is said to be dependent on human experience and intuition, so Fujitsu considers that ICT, rather than being used for improving efficiency, automating processes, and increasing productivity, must evolve into a human-friendly tool that helps to enhance a person's abilities and promote valuable life experiences.

2) Co-creation

While moving away from its traditional relationship as a corporate co-sponsor with sports organizations whose activities are centered on the common good, Fujitsu seeks to create new value through the fusion of sports know-how and technology and to construct a co-creation model that can maximize the managerial abilities of both Fujitsu and sports organizations.

3) Industrial revolution

Fujitsu will pursue the industrialization of the sports market and the creation of new fields by using data visualized by IoT and fostering innovation that can benefit athletes (playing), spectators and viewers (watching), and judges (supporting).

In addition, Fujitsu will promote the creation of a database of human movement through 3D sensing technology. It will also promote the construction of an open innovation infrastructure by enabling this database to be used not just by people in sports but also by people in a variety of fields and by providing a platform for creating new services.

8. Conclusion

We described Fujitsu's role in the field of sports and its efforts in gymnastics judging support through 3D sensing technology as a specific example of fulfilling that role.

We aim to expand this technology refined in gymnastics to other sports and a variety of fields such as healthcare, assistance for disabled persons, healthy life expectancy, industry, and culture. Through sports, we would like to enable everyone in the world to be mentally and physically healthy and lead a culturally enriched social life.

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